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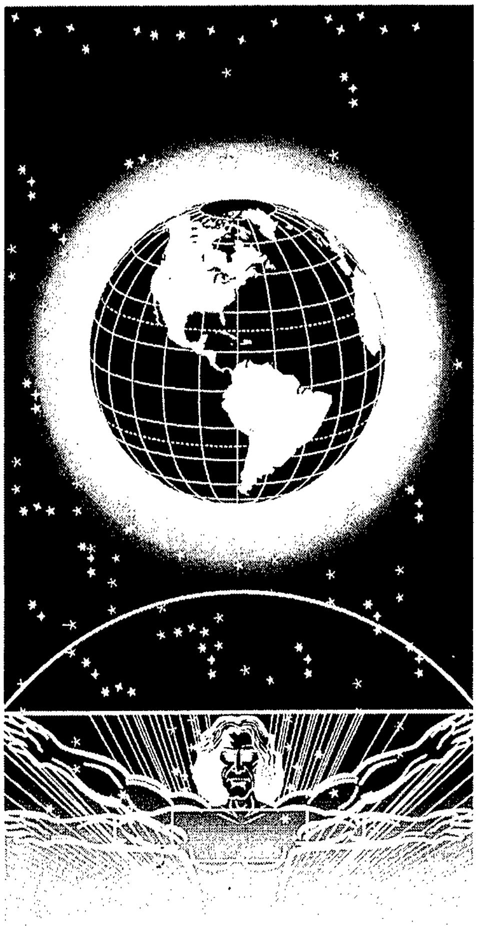

UNITED STATES AIR FORCE RESEARCH LABORATORY

VALIDITY OF SUBMAXIMAL CYCLE ERGOMETRY FOR ESTIMATING AEROBIC CAPACITY

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This report has been reviewed and is approved for publication.

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14. ABSTRACT
The accepted method for determining maximal oxygen consumption is collection and analysis of expired gases which has been limited to the research laboratory. Although a variety of tests may be more practical, the relative safety, validity, and reliability has been a concern. To simplify the Wahlund/Astrand-Rhyming protocols to enhance test precision as well as making it reasonable for the non-technically trained test administrator, a procedure has been developed that allows early selection of the most appropriate test work load. A computerized version makes it possible for non-trained personnel to safely administer this test for estimating aerobic capacity. This study critically evaluates the relationship between estimates of maximal oxygen consumption by a specific cycle ergometer protocol and (1) values obtained by the criterion method employing indirect calorimetry and exhaustive treadmill exercise, and (2) the very high and very low levels of aerobic capacity that are implicit for competitive endurance athletes and for documented sedentary adults, respectively.

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INTRODUCTION

I. Measuring Cardiovascular Fitness

Since it was first measured by Sid Robinson[11] in the 1930s, the validity of maximal oxygen consumption ($\dot{V}O_{2\,max}$) as the best single indicator of cardiovascular fitness remains unequivocal. The most widely accepted method for *determining* $\dot{V}O_{2\,max}$ is the collection and analysis of expired gases, i.e. indirect calorimetry, during the final minutes of an exhausting bout of treadmill exercise. Unfortunately, the application of this method has been generally limited to the research laboratory because of its relatively high cost, demanding technology, and the significant risk that it imposes on those who may not enjoy perfect cardiovascular health. Consequently, this technology has not been routinely available for use in career fields where the screening or classification of individuals according to overall fitness or functional capacity should be considered of paramount importance in the selection process.

Although Robinson's method for determining $\dot{V}O_{2\,max}$ by indirect calorimetry is not practical for application to large numbers of people, his work at the Harvard Fatigue Laboratory[11] helped to establish some of the critically important physiological principles that can be applied to alternative methods for assessing cardiovascular capacity or $\dot{V}O_{2\,max}$. Among these are the following:

- *Exercise heart rate increases in direct proportion to increases in work load* (i.e. increases in metabolic rate as measured by oxygen requirement).

- An *increase in the capacity of working muscles to utilize oxygen is largely dependent upon the cardiovascular system's ability to increase the delivery of oxygenated blood* to meet the increasing demand.

- The *maximal limit for consuming oxygen,* which occurs upon or just before reaching a maximal heart rate during exhaustive exercise, *coincides with the maximal delivery of oxygenated blood to the working muscles.*

- *Heart rate increases* rapidly during the first minute(s) of exercise, *reaching a plateau (i.e. steady state) between the third and fifth minutes* of constant submaximal exercise.

- *Stroke volume,* which increases with metabolic rate, *plateaus at low levels of submaximal exercise. Thus, further increases in cardiac output,* i.e. to meet the metabolic needs of strenuous and/or exhausting exercise, *are primarily a function of increases in heart rate.*

- *Maximal heart rate (HR max) decreases as a function of age;* from a youthful high of 200+ beats per minute (bpm), HR max decreases at a rate of approximately 10 bpm per decade in the aging process.

- An individual's aerobic *capacity (i.e.* $\dot{V}O_{2\,max}$*) can be estimated as a function of relative heart rate during a given bout of submaximal work;* the more fit individual will exhibit a lower heart rate which indicates a higher heart rate reserve at any given level of submaximal exercise.

- *Heart rate at any given* level of *sub-maximal exercise decreases with physical training that is strenuous enough to increase* $\dot{V}O_{2\,max}$. Thus, in the trained individual, a decrease in heart rate during a standard bout of submaximal exercise suggests an increase in stroke volume, i.e., an increase in both the efficiency and the overall functional capacity of the cardiovascular system.

Based on these principles, a variety of tests which analyze heart rate responses either during or immediately following submaximal exercise have been developed over the years in an effort to more safely and conveniently provide an *estimate* of $\dot{V}O_{2\,max}$. Although these tests may be more practical for application to large numbers of people, the relative safety, validity, and reliability of these tests remains a concern.

II. Estimating Cardiovascular Fitness

The scientific literature has repeatedly confirmed Robinson's physiological principles describing metabolic and cardiovascular responses of men to submaximal and maximal exercise, and these principles have been expanded to include women with supposedly equal validity. Wahlund[14] first applied these physiological principles in an attempt to develop a safe, submaximal test protocol that could validly estimate an individual's true $\dot{V}O_{2\,max}$. Utilizing a cycle ergometer to impose a precise work load, Wahlund developed an equation for calculating an "estimate" of $\dot{V}O_{2\,max}$ from steady state heart rate response to a specific metabolic requirement. Although certainly less expensive and imposing considerably less risk than the criterion method by indirect calorimetry, the application of Wahlund's protocol and equations were still limited to the physiologist or the highly-trained laboratory technician.

Astrand and Rhyming[4] simplified Wahlund's method by developing a nomogram for conveniently deriving $\dot{V}O_{2\,max}$ from exercise heart rate for a variety of work loads on a cycle ergometer. This nomogram provided an estimate of $\dot{V}O_{2\,max}$ for both men and women, and it was later improved when Astrand[3] published a table of correction factors which incorporated Robinson's finding that HR max decreases with age. These contributions by Astrand and Rhyming rekindled interest in Wahlund's concept, but their method still required a degree of technical ability and involved considerable trial and error in application. For example, these investigators simply recommended that (a) the exercise load imposed on a given individual should be high enough to elicit a heart rate response in excess of 125 bpm while not exceeding about 150 bpm, (b) the exercise should be limited to six minutes in duration, and (c) the steady state heart rate achieved during the last two minutes of exercise should be used in entering the nomogram for estimating $\dot{V}O_{2\,max}$. The difficulties with this method soon became obvious; although the authors recommended loads of 300 to 900 watts for males and 300 to 650 watts for females, the load selection really becomes a trial and error exercise even for the trained and experienced physiologist.

In an attempt to simplify the Wahlund/Astrand-Rhyming protocols in a manner that could enhance test precision as well as making it reasonable for the non-technically trained test administrator, Myhre[7] developed a procedure that allowed the early selection of the most appropriate test work load based on the rate of rise of the heart rate during the first three minutes of exercise. Subscribing to the well-established principles describing normal heart rate responses to exercise, this protocol establishes the most appropriate work load early in the test and then maintains that work load for six minutes to assure that the heart rate has reached a steady state. The average heart rate for minutes five and six was then used to enter the Astrand-Rhyming nomogram, incorporating the appropriate age corrections to calculate an estimate of $\dot{V}O_{2\,max}$. The high correlation achieved ($r = 0.93$) by this method[7] for physically fit young men when validated against $\dot{V}O_{2\,max}$ determined by indirect calorimetry for maximal exercise was indeed promising; mean values estimated from this submaximal test and those determined from maximal exercise with indirect calorimetry were 48.5 ± 3.61 and 47.4 ± 4.02 ml/kg/min, respectively[7]. Although technically demanding in its basic form, Myhre[8] developed a computerized version of this test protocol making it possible for non-trained personnel to safely administer this test for validly estimating aerobic capacity.

The purpose of this study will be to critically evaluate the relationship between estimates of $\dot{V}O_{2\,max}$ by this specific cycle ergometer protocol and (1) values obtained by the criterion method employing indirect calorimetry and exhaustive treadmill exercise, and (2) the very high or very low levels of aerobic capacity that are implicit for competitive endurance athletes and for documented sedentary adults, respectively.

EXPERIMENTAL DESIGN

This study was designed to evaluate the safety, validity, and the reliability of a specific computer-guided cycle ergometry test protocol for estimating $\dot{V}O_{2\,max}$ in a heterogenous group of military-age men and women.

I. Safety

Tests involving physical exercise to the point of exhaustion impose significant risk to those who may have less than perfect cardiovascular health. The overall mortality rate involving 170,000 *maximal exercise stress tests* performed by 73 medical centers prior to 1971 has been reported as one death per 10,000 tests, and the rate of serious cardiac complications as four per 1,000[6].

On the other hand, tests that impose only moderate or submaximal exercise are considered to be quite safe. More than 10 years of experience in administering submaximal exercise tests to millions of people in the U.S. and in Canada has demonstrated this safety. Not a single death nor complications more serious than minor muscle injury and a few reports of syncope[2] were attributable to these tests. Indeed, the American Heart Association' and the American College of Sports Medicine[2] concur that those asymptomatic with respect to heart disease should be advised to exercise regularly, for 15 to 60 minutes at an intensity of up to 85% of estimated maximal heart rate. This so-called "exercise prescription" is intended for an apparently healthy population without the need for either medical clearance or medical supervision. Thus, it is reasoned that an exercise test limited to a few minutes at an intensity which elicits up to 85% of estimated maximal heart rate should be considered as safe and requiring no medical supervision.

II. Reliability

Human variability precludes the expectation of absolute replication of physiological responses to exercise. However, this variability can be minimized by proper control of both the test environment and by the subjects' attention to details outlined for proper preparation for each test. To this end, subjects were instructed to report to the research laboratory following a normal night's sleep. Strenuous exercise was to be avoided for at least 12 hours prior to testing and the subjects were asked to refrain from food intake for at least 4 hours prior to testing. Neither stimulants (e.g., caffeine, nicotine, etc.) alcohol, nor medication that could influence heart rate were to be taken within the period of time that could affect the steady state heart rate values achieved during the cycle ergometry test. All tests were to be conducted in a quiet, private environment maintained at normal room temperature ($23.0 \pm 1.0°$ C). Under these controlled conditions it was planned to administer each exercise test in triplicate, on different days. Statistical analyses of the data were designed to determine the reliability of repeated measures obtained from a given test administered to an individual on different test days.

III. Validity

The measurement of maximal oxygen consumption by indirect calorimetry during maximal (exhaustive) treadmill exercise has been well-established as the criterion method for determining true aerobic capacity or $\dot{V}O_{2\,max}$. Aerobic capacity was to be *determined* by indirect calorimetry for three separate treadmill experiments with the subject exercising to voluntary exhaustion. Scores for these determinations would then be compared with those estimated from heart rate response to submaximal cycle ergometry also performed in triplicate on three different test occasions. Thus, the validity of estimating $\dot{V}O_{2\,max}$ by heart rate responses to submaximal cycle exercise was dependent upon how well this estimate compared with the criterion method. Statistical analyses for testing this relationship would include the analysis of variance (and Duncan's multiple range test), Pearson Product Moment Correlation, and concordance of values between the criterion and the experimental variables. $P \leq 0.05$ was the level selected for determining statistical significance.

It is also well-established that a high level of physical performance in what may be termed an "aerobic" athletic event (e.g., running race in distances exceeding one mile) *is practical and objective evidence of a high level of cardiovascular fitness.* Thus, it was indeed fortunate that events made possible the estimate of aerobic capacity for competitive athletes and for retired athletes who continue to maintain fitness training regimens were obtained from the cycle ergometry test administered on a single occasion.

It is similarly well-established that $\dot{V}O_{2\,max}$ decreases progressively with age, with an accelerated decrease for those adopting a sedentary lifestyle. This decline in cardiovascular fitness is most evident in those whose lack of physical activity is accompanied by chronic disease. For this reason cycle ergometer tests were also administered to a group of obviously low-fit, elderly diabetic patients. Although not lending themselves to a precise statistical comparison with actual laboratory determinations of aerobic capacity, all of the athletes would be expected to score well, and the sedentary patients would be expected to score poorly on any valid test of cardiovascular fitness.

METHODS AND PROCEDURES

I. Experimental Evaluation of Cycle Ergometry

Volunteer subjects included 58 males and 41 females ranging in age from 20 to 57 years. Most of these civilian and military subjects volunteered out of simple interest in learning from the physiological tests which accurately described their fitness status. Some of the military subjects (17 of the males and 8 of the females) were in a sense "self-selected", entering this study on their own initiative and were anxious to participate because they had been particularly discouraged by and/or skeptical of their low scores for $\dot{V}O_{2\,max}$ estimated from this same cycle test which was adopted as the official Air Force cycle ergometry testing program on 1 Oct 92. Inclusion of "special cases" caused concern with respect to sample bias; these particular subjects could be expected to occur in any large population, but they are probably disproportionately represented in this small sample. In spite of this concern, the data obtained from the latter self-selected subjects were included in all statistical treatments.

All subjects were briefed concerning the details involved in every aspect of this study, and after signing an advised consent form, were given both a Class III flight physical and a resting echocardiogram prior to receiving clearance to participate.

A. Determinations of $\dot{V}O_{2\,max}$ by Exhaustive Treadmill Exercise: Maximal oxygen consumption ($\dot{V}O_{2\,max}$) in milliliters per kilogram of body weight per minute (ml/kg/min) was determined by classic calorimetric techniques[15]. Expired air, collected in Douglas bags during the last 45 seconds of each of the last four minutes of exercise, was transferred to a 120-liter Tissot gasometer for accurate volume measurement. An aliquot of the mixed expired air was obtained directly from the Douglas bag and the concentrations of oxygen and carbon dioxide were analyzed on a Perkin-Elmer mass spectrometer calibrated against standard gases as determined by micro Scholander and/or Haldane apparatus gas analyzers. Minute ventilation and oxygen consumption were calculated according to the standardized gas laws for indirect calorimetry.

Treadmill protocols were individually designed to progress gradually from easy to exhausting exercise within a period of 15 minutes or less. Speed of walking or jogging was predetermined during practice trials on the treadmill according to each individual's capability and acceptance. Once determined, speedwas kept constant and the treadmill grade was increased every minute to the point of volitional fatique/exhaustion. Beginning with 0% grade, the incline was increased to 5% at the end of the first minute. Thereafter, the grades for walkers increased to 10% and 15% at the end of minutes two and three, respectively. Grades then increased 1% every minute until the subject quit with exhaustion. The schedule of grade increases was the same for the joggers except that the transition from increments of 5% to 1% per minute commenced once the subject's exercise heart rate had reached 80% of his/her predicted maximal heart rate. Subjects unable to complete at least three minutes of exercise during the period when grade increases were 1% per minute were rescheduled and the protocol adjusted accordingly.

B. Estimates Of $\dot{V}O_{2\,max}$ by Cycle Ergometry: The test protocol developed by Myhre[7] was administered in strict accordance with the procedures described in AFP 92-3[8]. The calculation of the estimated $\dot{V}O_{2\,max}$ was accomplished by a computer program according to the algorithms developed by Myhre[7] as they appear in the official US Air Force Firefighter Fitness Test and the US Air Force Cycle Ergometry Fitness Test software programs (version 3.0, 1992); see Appendix I of this report. Heart rate response to precise, submaximal exercise is the physiological basis for estimating $\dot{V}O_{2\,max}$ by cycle ergometry. The determination of each individual's normal resting heart rate was an important reference for the ultimate evaluation of normality in heart rate response to exercise, and this was determined under controlled conditions employed in classic basal metabolism experiments[5].

II. Practical Evaluation of Cycle Ergometry for Estimating Cardiovascular Fitness

In addition to subjecting the estimate of $\dot{V}O_{2\,max}$ by cycle ergometry to validation against the experimental criterion, studies running concurrently offer additional insight of a more practical nature. For example, athletes in training to compete in events that require cardiovascular fitness would be expected to score well on a test for $\dot{V}O_{2\,max}$; elderly sedentary men and women, particularly those who also happen to be diabetics, would be expected to score low on this test. Since there can be no question whatever in the great differences between these two groups' cardiovascular capacity (i.e., physical capability to perform very strenuous physical tasks without fatigue), including them in this study would allow cycle ergometry the opportunity to clearly fail as a practical or "common sense" screening test for physical fitness.

A. Test Results for Performing Competitive Athletes: Aerobic capacity was estimated by the cycle ergometry procedure in a group of one female and 17 male military athletes. These tests were administered on a morning following 11 eight-plus hour days of intense physical training in preparation for international competition. Thus, it was anticipated that some of these athletes may have been experiencing varying levels of fatigue at the time these tests were administered. In addition, these same tests were administered to six of the athletes' coaches; although no longer competing, all were former athletes who had maintained a high degree of fitness through regular participation in both strength and cardiovascular fitness exercise regimens.

B. Test Results for Sedentary/Diabetic Adults: Estimates of $\dot{V}O_{2\,max}$ were obtained from this particular cycle ergometry test administered to 79 male and female patients at Wilford Hall Medical Center[13]. These tests were administered under the same controlled conditions described for the laboratory experiments in this study.

RESULTS

I. Experimental Evaluation of Cycle Ergometry: Bioclinical characteristics of the 58 male and 41 female volunteer subjects are summarized in Table 1.

Table 1. Bioclinical Characteristics of Experimental Subjects

Subject	Age (Yrs)	Height (cm)	Weight (Kg)
Males (n=58)			
Mean	33.5	178.1	79.94
S.D.	9.7	7.1	11.13
Minimum	20	160	49.1
Maximum	57	194	129.4
Females (n=41)			
Mean	33.2	163.4	63.31
S.D.	7.3	6.9	11.62
Minimum	21	151	43.5
Maximum	50	177	106.6

Subjects represented populations which ranged from sedentary to competitive athletes in the proportions described below:

<u>Sedentary Moderately Active Active Competitive</u>

Males	10 (17%)	18 (31%)	20 (34%)	10 (17%)
Females	22 (54%)	9 (22%)	7 (17%)	3 (7%)

A. Test Safety: The relative stress imposed on the cardiovascular system during the administration of the submaximal cycle ergometry test can be expressed in terms of the highest heart rates achieved during that test. In this study, a test resulting in heart rates that either fall below or exceed the criterion values (i.e., a minimum of 125 bpm and a maximum of 85% of estimated maximal heart rate) was considered invalid and was repeated on another day. First-time tests for seven (12%) of the male and four (10%) of the female subjects in this study were invalid due to these criteria; they were then repeated at the appropriate work load on another day as directed by the computer software guiding these experiments. All of these retests were valid by these heart rate criteria and a summary of the entire data set is presented in Table 2.

Table 2. Mean Heart Rate Values Achieved During Minutes Four Through Six of Computer Guided Submaximal Exercise on a Cycle Ergometer.

		Exercise Minute			Percent Maximal Heart Rate	
		4	5	6	Estimated*	Determined**
Male	Mean	137.5	140.0	140.6	76.9	74.3
(n=58)	S.D.	8.9	9.4	9.7	5.7	5.2
Female	Mean	140.8	142.9	143.9	77.8	75.6
(n=41)	S.D.	9.1	9.3	9.3	4.7	5.0

Analysis of Variance: Significant differences exist in heart rates observed during minutes 4-6 for both the male and female subjects.
Duncan's Multiple Range Test: The difference between any two heart rates observed during minutes 4-6 for both male and female subjects is significant at $p<0.05$.
*Mean of maximal values observed during minutes 4-6;value presented as a % of estimated maximal heart rate (i.e., 220 - age)
**Percent of true maximal heart rate determined during maximal treadmill tests

It can be noted that the mean heart rates increased slightly, but significantly, during each of the last three minutes of exercise for both gender groups. Heart rates observed at the end of minutes four, five, and six differed significantly for both the male and female subjects ($P<0.05$). Indeed, Duncan's multiple range test indicated that the difference between any two heart during this stage of the test was significant at $P<0.05$. The greatest differences were between minutes four and five, averaging only 2.5 bpm and 2.1 bpm for the males and females, respectively.

Highest heart rates achieved during these tests averaged 76.9% and 77.8% of *predicted maximal heart rates* for the males and females, respectively. Although these values lie well within the safety criterion of 85% of predicted maximal heart rate, the safety of this test becomes even more impressive when these data are *compared to percent of the maximal heart rates actually determined* during the exhaustive treadmill tests (see Table 2). Analyzed in this manner, highest heart rates achieved during the cycle tests really averaged only 74.3% and 75.6% of the determined maximal heart rate values for these subjects. Although the safety feature suggested by these data was impressive, reporting only mean values hides the highest individual values observed during the test. For this reason, all heart rates that exceeded 85% of either the predicted or the determined maximum were tabulated and summarized in Table 3.

Table 3. Individual Heart Rates Exceeding 85% of Maximal Heart Rate During the Six Minute Cycle Ergometer Test.

	Exercise Heart Rate	% of Predicted HR max	% of Determined HR max
Male	180	94.5	83.9
Male	168	85.3	79.6
Male	154	85.8	82.5
Male	157	93.5	86.3
Male	153	85.2	82.0
Female	162	85.3	83.9
Female	161	85.4	83.6
Female	156	82.1	85.2

Table 3 shows that in only seven experiments did cycle exercise elicit a heart rate that exceeded 85% of predicted maximal heart rate, and in five of these the heart rates observed were less than 86% of predicted maximum. More impressively, there were only two cases in which heart rate slightly exceeded 85% of the actually determined maximal heart rate. Again, even the highest individual heart rates observed in these experiments were found to be within two beats of the safety limits established for this testing.

B. Test Reliability: The test-retest variability observed for these maximal treadmill and submaximal cycle ergometer experiments are summarized in Tables 4 and 5.

Table 4. Treadmill Determinations of $\dot{V}O_{2\,max}$ (ml/kg/min) Obtained from Triplicate Experiments Conducted on Separate Days. (Mean ± S.D.)

	Male (n=37)	Female (n=34)
Test #1	45.91 ±10.84	35.75 ±7.55
Test #2	46.96 ±10.84	35.85 ±7.06
Test #3	46.99 ±10.62	36.46 ±7.20
ANOVA	p = 0.001	p = 0.072

1. Maximal Treadmill Tests - Mean Responses: Table 4 shows that 71 of the 99 subjects were available to complete all three of the treadmill experiments. The values for $\dot{V}O_{2\,max}$ increased slightly after the first test for both the male and the female subjects. Two-way analysis of variance indicated that these differences were significant for the male subjects only; subsequent analysis by Duncan's Multiple Range test identified that the first test was significantly lower than either tests two or three, and the latter were not different. Although statistically significant, there was little practical significance in even the greatest average difference between any of the tests which was only 1.08 ml/kg/min. For the females, the greatest difference between any two tests was only the increase of 0.71 m/kg/min between the first and the third treadmill test. This difference was neither statistically nor practically significant. Thus, test scores tended to improve slightly after the first try for both gender groups, and these improvements were only significant for the male subjects.

Table 5. Cycle Estimates of $\dot{V}O_{2\,max}$ (ml/kg/min) Obtained from Triplicate Experiments Conducted on Separate Days. (Mean ± S.D.)

	Male (n = 38)	Female (n = 39)
Test #1	41.72 ±12.84	35.52 ±11.33
Test #2	42.91 ±12.44	36.32 ±11.31
Test #3	43.08 ±11.60	37.08 ±11.48
ANOVA	p = 0.036	p = 0.006

2. Submaximal Cycle Tests - Mean Responses: Table 5 shows that 77 of the 99 subjects were available to complete the cycle ergometry tests in triplicate. As was the case for the treadmill tests, the values for estimated $\dot{V}O_{2\,max}$ also tended to increase with repeated trials. For the males, scores for the second test were significantly higher than those for the first by an average of 1.19 ml/kg/min, but only increased 0.17 ml/kg/min for the third test. For the females, there was a general increase over the three tests, but only the first and third tests differed significantly, by 1.56 ml/kg/min. Thus, estimates of $\dot{V}O_{2\,max}$ by cycle ergometry tend to increase slightly, but significantly, after the first test for the male and after the second test for the female subjects.

Tables 4 and 5 illustrate the potential of a trend or a learning effect observed when men and women are repeatedly exposed to either maximal treadmill or submaximal cycle tests. Indeed, it appears that something is likely to be gained when these individuals are given a second or a third attempt, but the average differences do not appear to be very impressive. Nevertheless, since they were statistically significant, they must not be ignored. Although this potential "learning effect" may be worrisome, it can be put in better perspective by studying the actual values achieved by the individual subjects in repeated treadmill and cycle tests as will be discussed below.

3. Repeated Maximal Treadmill Tests - Individual Responses: Whenever personal schedules would allow, subjects were afforded up to three opportunities to achieve a maximal effort on the treadmill tests. The intrasubject variability for repeated measures of aerobic capacity by the criterion (treadmill) method is presented in Figures 1 and 2. Individuals that demonstrated variability greater than 5 ml/kg/min among these replicated tests are highlighted by a rectangle enclosing their test scores.

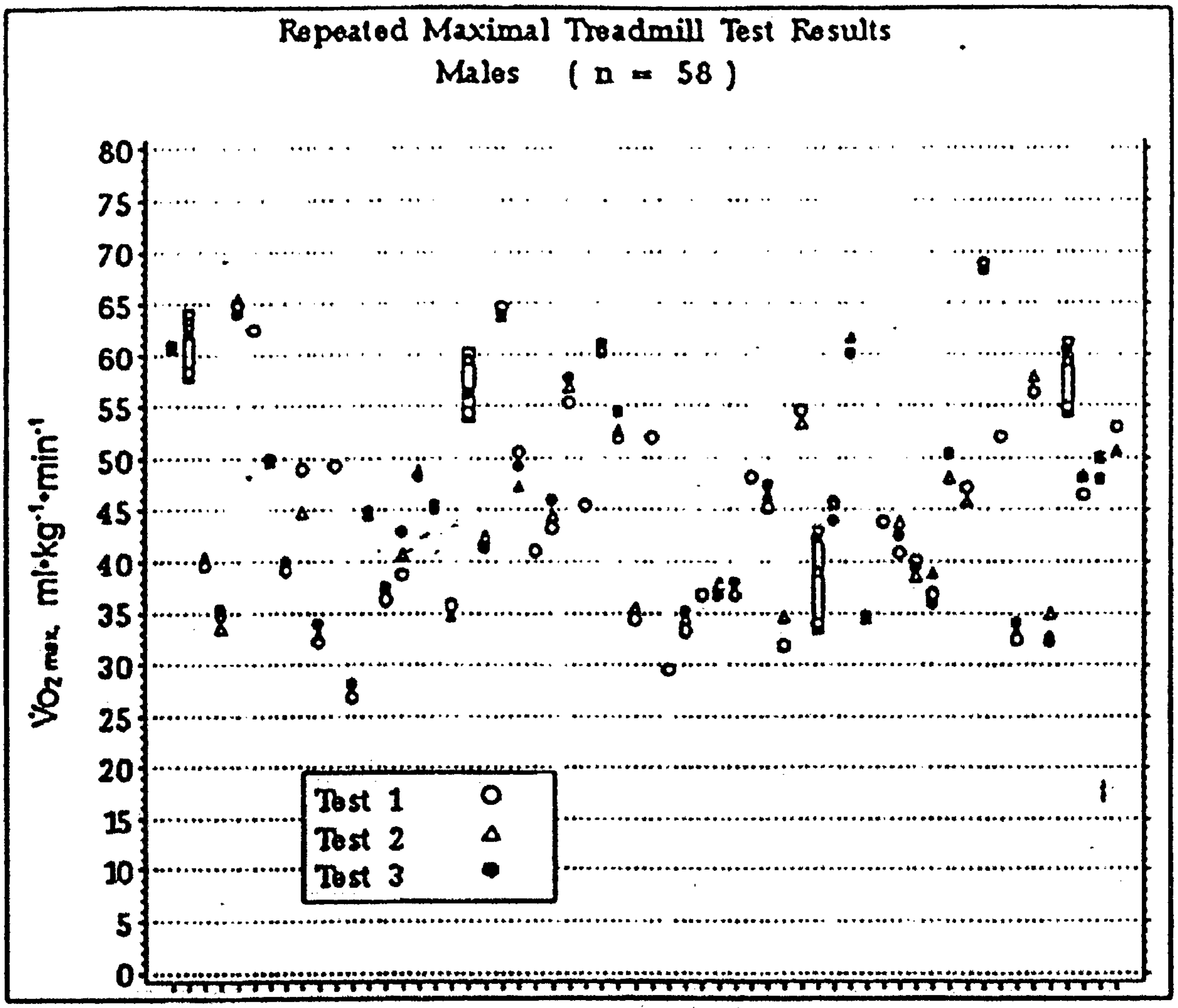

Figure 1. Individual scores plotted for 58 male subjects making multiple attempts to achieve $\dot{V}O_{2\,max}$ during maximal treadmill exercise experiments. Subjects with scores differing by more than 5 ml·kg^{-1}are enclosed in rectangles.

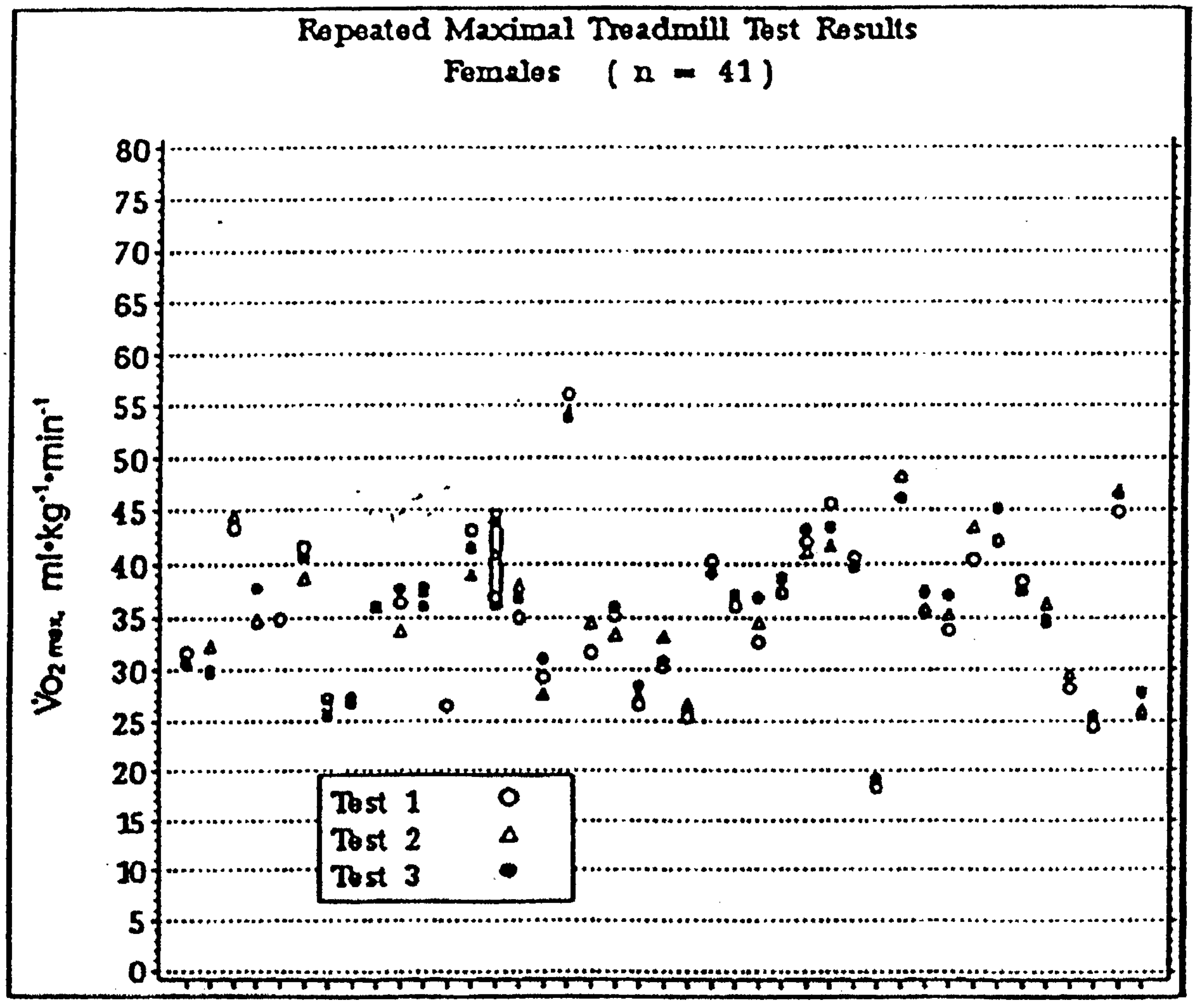

Figure 2. Individual scores plotted for 41 female subjects making multiple attempts to achieve $\dot{V}O_{2\,max}$ during maximal treadmill exercise experiments. Subjects with scores differing by more than 5 ml·kg^{-1}are enclosed in rectangles.

Figures 1 and 2 show that the agreement between test-retest scores for maximal treadmill exercise for most of the subjects was reasonably good. Only one female and four male subjects exhibited variability greater than 5 ml/kg/min in these experiments. Although inconsequential for most subjects, the data plotted here confirm the summaries presented in Table 4, namely, that the first attempt at a maximal treadmill test yielded a slightly lower score for most subjects of both genders. Differences exceeding 5 ml/kg/min, when they occur, are of both statistical and practical significance; hence variability in repeated human responses exists for even the criterion measure of aerobic capacity.

4. Repeated Submaximal Cycle Tests - Individual Responses: The individual values for each of the repeated submaximal cycle tests are plotted in Figures 3 and 4.

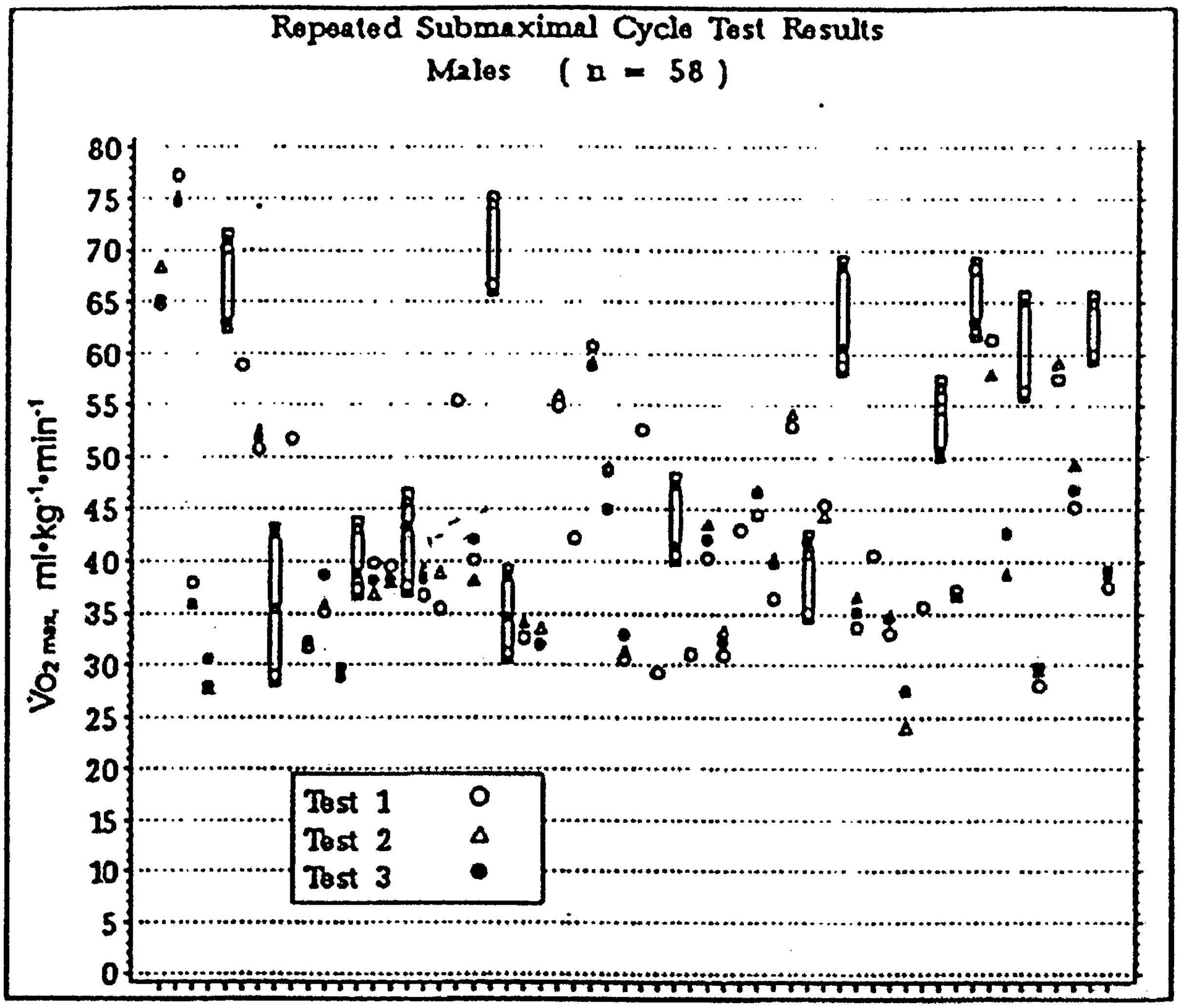

Figure 3. Individual scores plotted for 58 male subjects multiple experiments to estimate $\dot{V}O_{2\,max}$ by submaximal exercise on a cycle ergometer. Subjects with scores differing by more than 5 ml·kg^{-1}·min^{-1} are enclosed in rectangles.

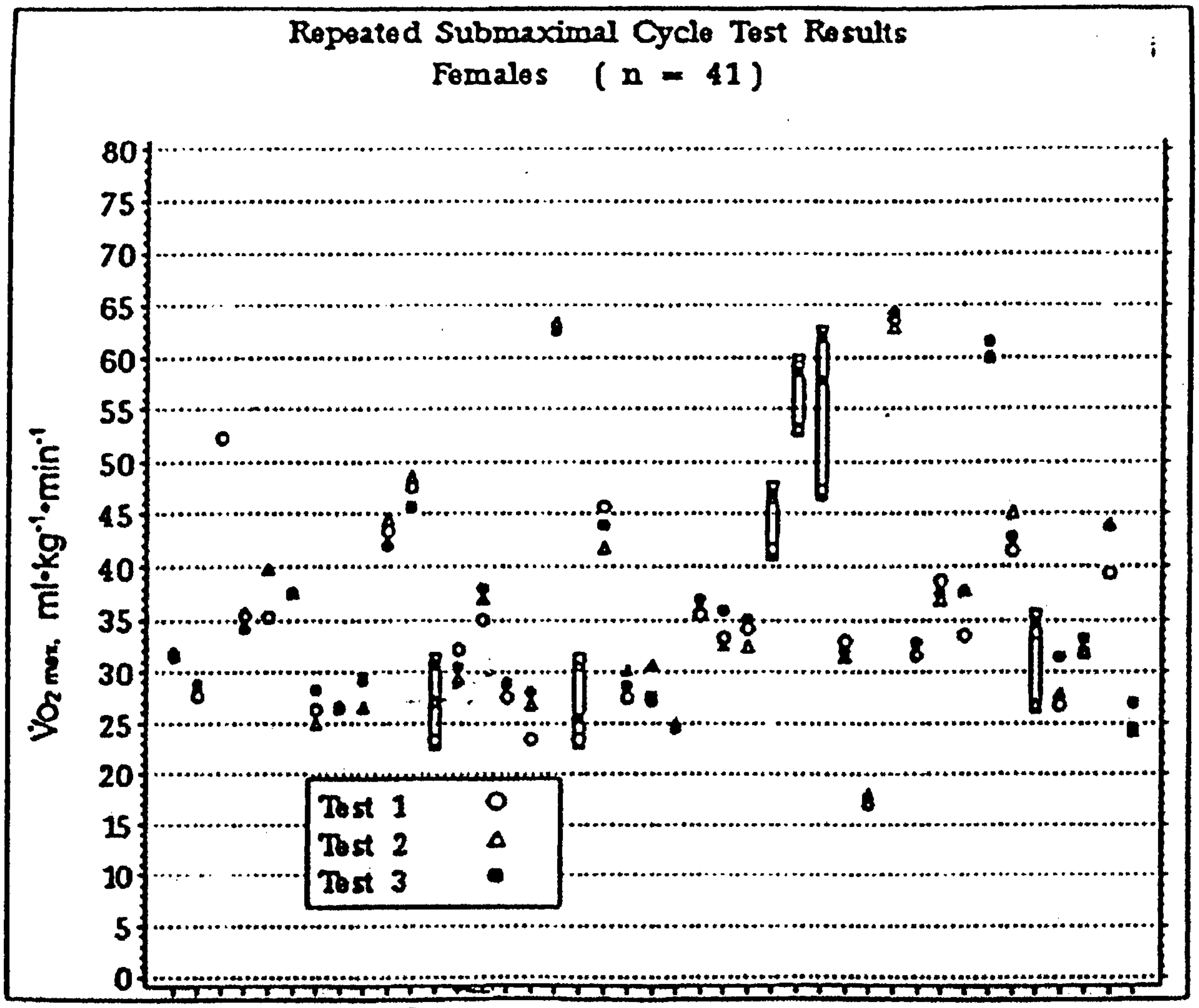

Figure 4. Individual scores plotted for 41 female subjects multiple experiments to determine $\dot{V}O_{2\,max}$ by submaximal exercise on a cycle ergometer. Subjects with scores differing by more than 5 ml·kg^{-1}·min^{-1} are enclosed in rectangles.

Figures 3 and 4 illustrate a greater incidence of discrepancy between test-retest scores estimated from submaximal exercise than that observed for maximal treadmill exercise. Six of the females and 13 of the males exhibited differences greater than 5 ml/kg/min in these experiments. It may be significant to note that in 11 of these 19 subjects, this level of discrepancy disappeared after taking the cycle test for the first time. By comparison, all five of the discrepancies exceeding 5 ml/kg/min in repeated treadmill scores were eliminated after the first test. The root mean square error for scores achieved on multiple exercise tests illustrates the individual variability to be expected for a given test. These analyses are summarized in Table 6.

Table 6. Comparison of Individual Variability (Root Mean Square Error) in Scores Achieved in Multiple Treadmill and Cycle Tests.

	Treadmill	Cycle
Males (n = 58)	1.405	2.599
Females (n = 41)	1.392	2.201

Root mean square error (RMSE) is derived from an analysis of repeated measures performed on a large number of individuals. It can be used to describe the degree of confidence that can be assigned to any given score when a test is given just one time to a given individual. For example, one can be 95% confident that an individual's true score will be within plus or minus two times the RMSE of his observed treadmill or cycle score. Thus, if a male scores 46.0 ml/kg/min on either of these tests, one can be 95% confident that his true score would be between 46.0 $\pm$ 2 x 1.41 for the treadmill and 46.0 ± 2 x 2.60 for the cycle. Stated another way, from a single test score of 46.0 ml/kg/min, one would be highly confident that repeated tests would confirm that this individual's true score would be not less than 43.2 nor higher than 48.8 ml/kg/min for the treadmill, and not less than 40.8 nor higher than 51.2 ml/kg/min for the cycle test. As an example, it is highly unlikely that an individual scoring less than 46.0 ml/kg/min on a given cycle test would ever score higher than 51.2 with repeated tries at that test.

C. Test Validity: The median value of the three test scores achieved by both maximal treadmill determinations and submaximal cycle estimates of $\dot{V}O_{2\,max}$ was deemed to be the most valid and appropriate measure for testing validity. The analyses of these median values for male and female subjects are presented in Table 7.

Table 7. Relationship Between Median Aerobic Capacity Scores (ml/kg/min) Achieved from Repeated determinations by the Treadmill Test and Estimates by Cycle Tests. (Values are Means ±S.D.)

	Treadmill	Cycle	Mean Diff	Probability	Correlation	Concordance
Males (n=58)	46.11 ±10.02	44.76 ±12.25	-1.35	0.098	0.87	0.84
Females (n=41)	35.58 ±7.17	36.91 ±11.48	1.33	0.232	0.81	0.72

From Table 7 it can be seen that treadmill determinations and cycle ergometry estimates of $\dot{V}O_{2\,max}$ for the male subjects averaged 46.11 ± 10.02 and 44.76 ± 12.25 ml/kg/min respectively. The mean difference between these two measures was small (-1.35 ml/kg/min) and it was not statistically significant. The correlation between treadmill and cycle scores was good (0.87) and the relatively high value for concordance (0.84) suggests that not only was there a good correlation between the two methods, but that the scores for a given subject tended to be nearly the same (i.e., no undue bias). Treadmill determinations and cycle estimate for female subjects averaged 35.58 ± 7.17 and 36.91 ± 11.48 ml/kg/min, respectively. Again, the mean difference of 1.33 ml/kg/min between these values was not significant. The correlation and concordance values for these test scores were 0.81 and 0.72, respectively.

In summary, cycle test scores tended to underestimate true $\dot{V}O_{2\,max}$ by an average of 1.4 ml/kg/min, for the males while overestimating true $\dot{V}O_{2\,max}$ by an average of 1.3 ml/kg/min, for the females. However, neither of these differences was statistically significant ($p<0.05$).

1. Maximal Treadmill Exercise as the Criterion Measure: Achieving a maximal heart rate is one criterion used to judge the validity of a maximal effort in treadmill tests to determine aerobic capacity. Robinson[11] was first to show that maximal heart rate declines with age, and from his early work, others suggested that maximal heart rate can be estimated as 220 - age. In the present study, actual peak heart rates achieved during the treadmill experiments were compared with those estimated for each subject and the results of these analyses are presented in Table 8.

Table 8. Highest Heart Rates Observed During Exhaustive Treadmill Exercise vs. Predictions of Maximal Heart Rate.

	Maximal Heart Rate	
	Predicted (220-age)	Determined

Male (n=58)	186.5 ± 9.7	193.1 ± 10.7
Female (n=41)	186.8 ± 7.3	192.6 ± 9.8

The average of the peak heart rates achieved during the maximal treadmill tests was significantly higher ($p < 0.05$) than the predicted maximal heart rate for both the male and female subjects. This result supports the conclusion that these exercises represented a maximal effort. The individual data which are graphically presented in Figures 5 and 6 also question the validity of the common equation of 220 - age for estimating maximal heart rate.

Treadmill Maximal Heart Rate vs. Age
Males (n = 58)

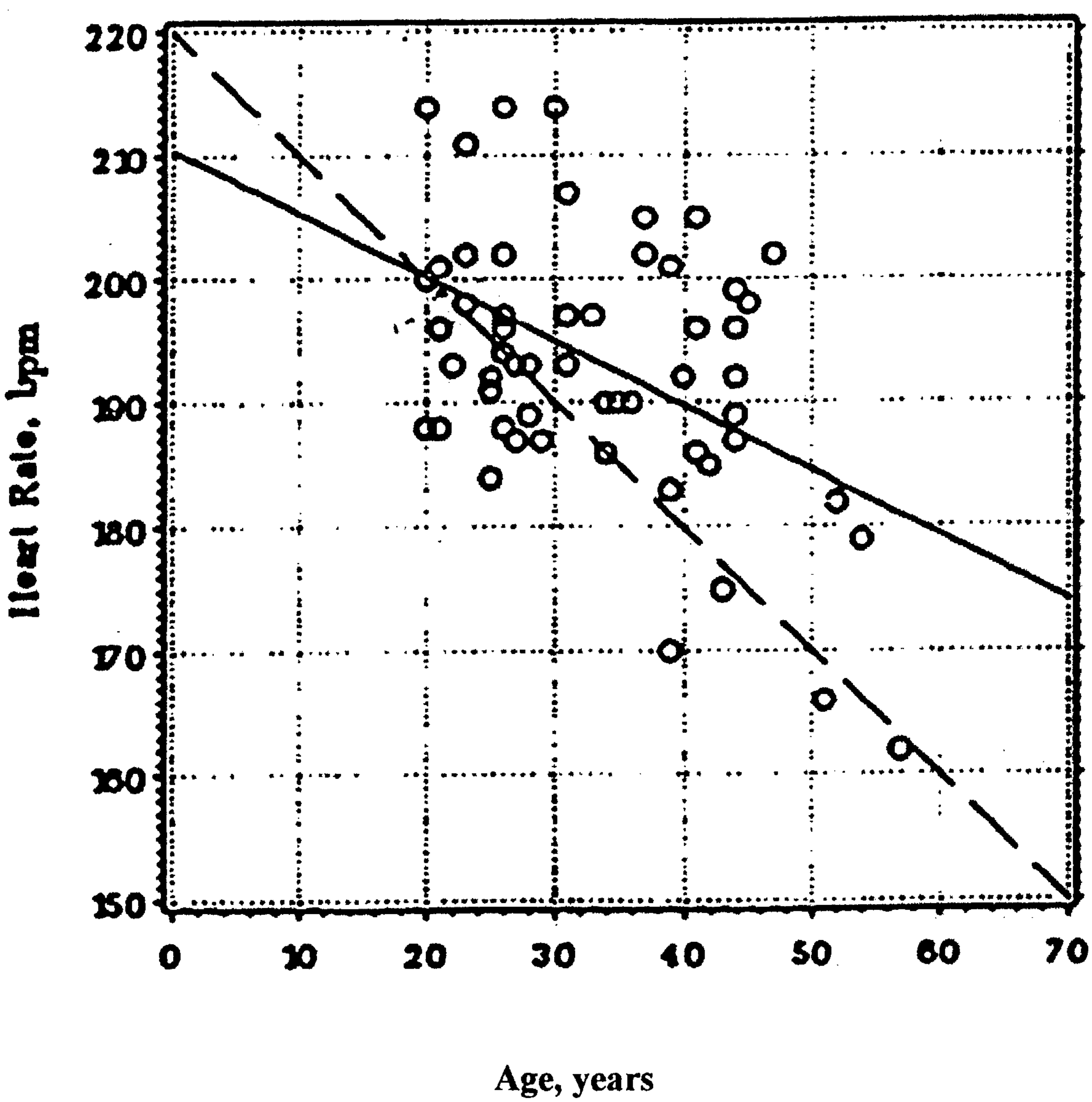

Figure 5. Maximal heart rate achieved during maximal treadmill exercise plotted as a function of age (solid line, r = -0.47) and compared with that predicted from the formula 220-age (dashed line).

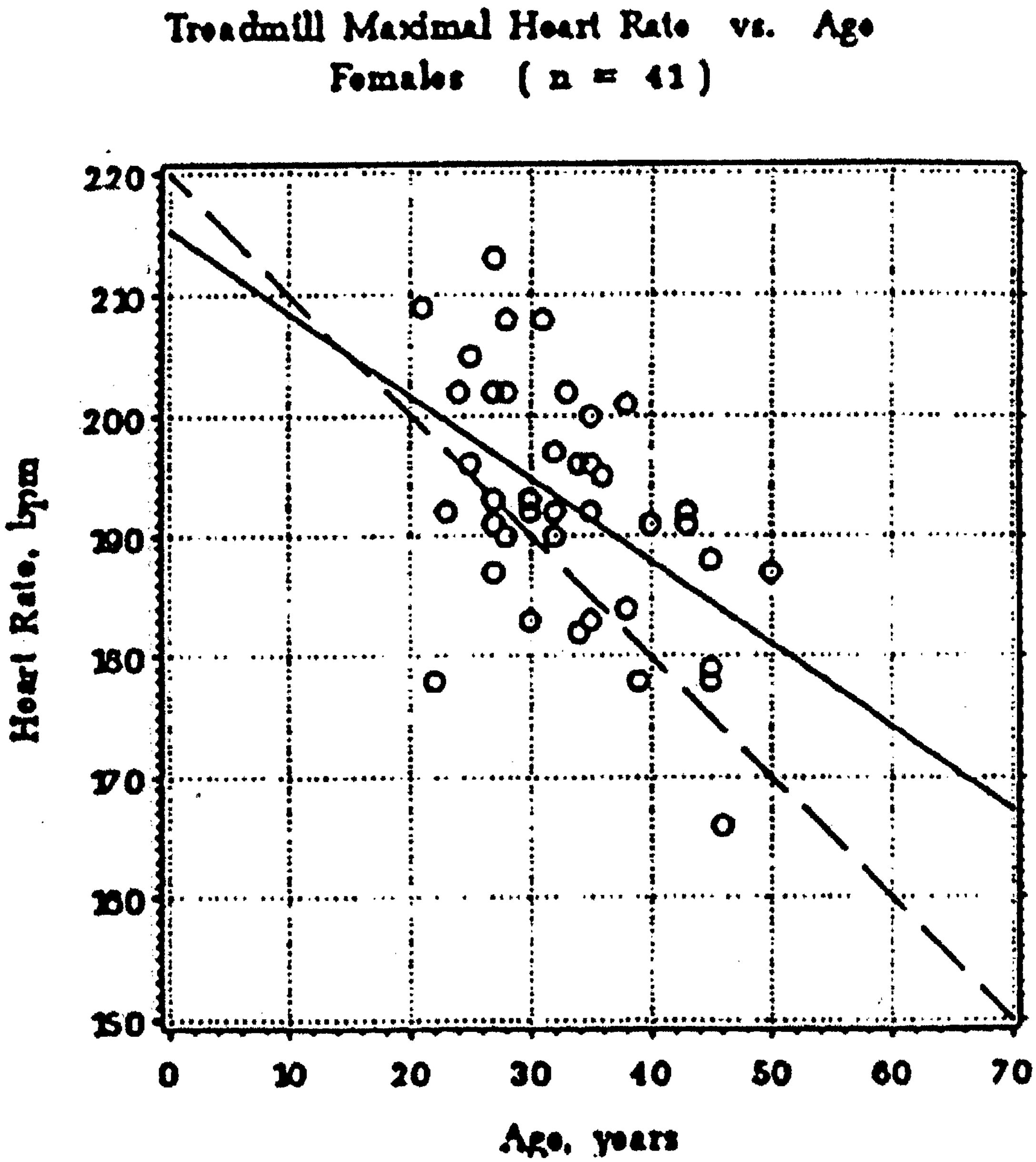

Figure 6. Maximal heart rate achieved during maximal treadmill exercise plotted as a function of age (solid line, r = -0.51) and compared with that predicted from the formula 220-age (dashed line).

The data in Figures 5 and 6 demonstrate that there is a relatively weak yet significant negative correlation between determined values for maximal heart rate and age. Although these data confirm the fact that maximal heart rate declines with age, the rate of decline was significantly less for our subjects than that predicted by the formula of 220 - age.

2. Discrepancies Between Treadmill Determinations and Cycle Estimates of $\dot{V}O_{2\ max}$: Based on the data summarized in Table 7 one may say that, statistically, there is no difference between median scores for $\dot{V}O_{2\ max}$. achieved by maximal treadmill experiments and by submaximal cycle ergometry. Although the means of these values did not differ, cycle estimates were not equally valid for all individuals as illustrated in Figures 7 and 8.

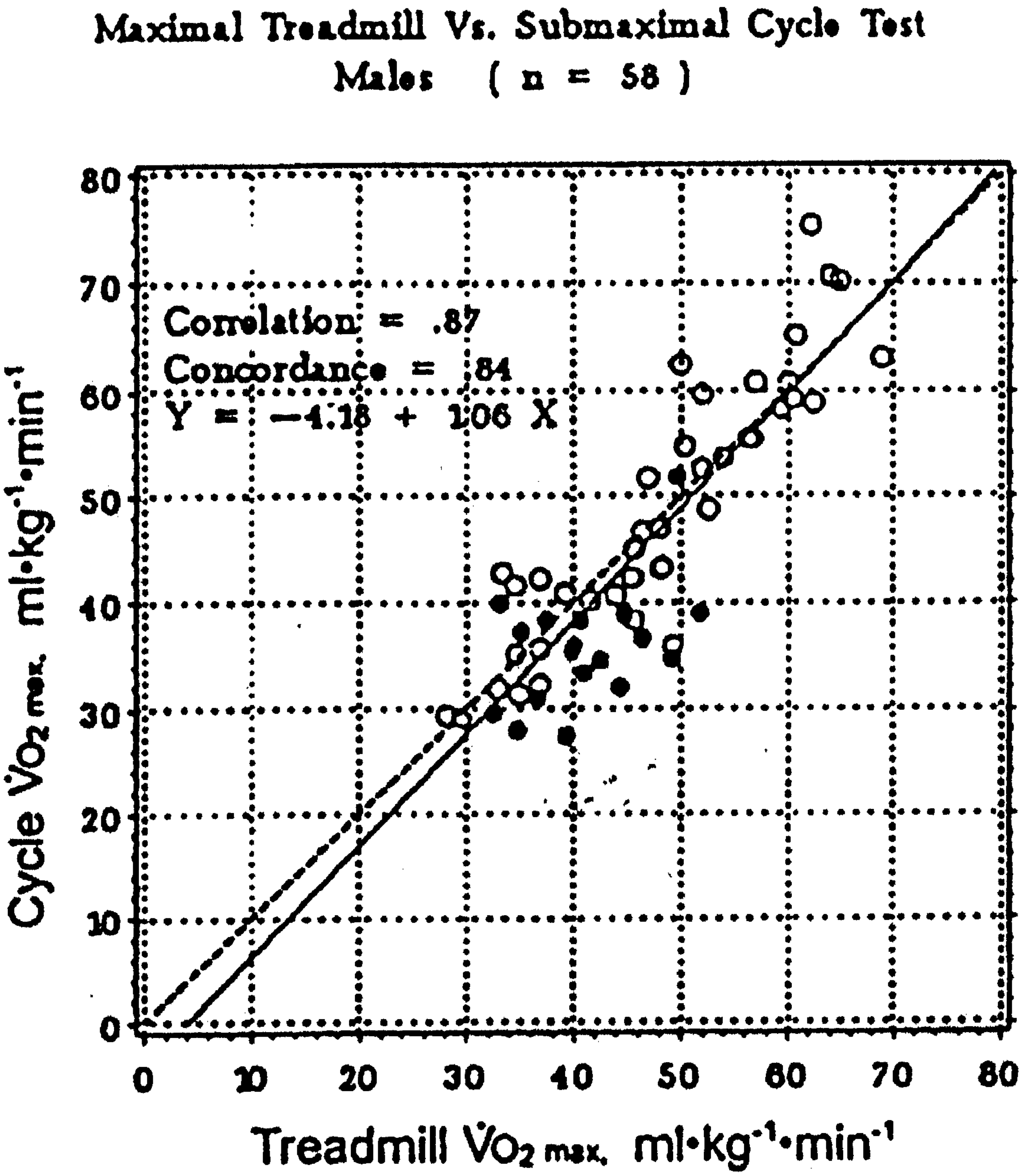

Figure 7. Median values for male $\dot{V}O_{2\ max}$ estimated by submaximal exercise on a cycle ergometer plotted against the criterion values determined by indirect calorimetry during maximal treadmill exercise and compared with the line of identity (dashed line). Filled circles are self-selected subjects.

The regression line describing the relationship between the criterion (treadmill) and cycle scores for the male subjects presented in Figure 7 is not significantly different from the line of identity. In spite of this seemingly excellent agreement between the two tests, cycle ergometry underestimated true $\dot{V}O_{2\,max}$ by more than 10 ml/kg/min in 5 of the 58 men; 2 other male subjects had cycle scores that overestimated true $\dot{V}O_{2\,max}$ values by a similar magnitude. On the other hand, although lacking in absolute terms, these data suggest that the cycle test accurately screens unfit (i.e., $\dot{V}O_{2\,max} < 30$ ml/kg/min) from highly fit (i.e., $\dot{V}O_{2\,max} > 50$ ml/kg/min) men. For example, only two of the males in this study were found to be truly unfit by the treadmill test (28.2 and 29.6 ml/kg/min) and they were correctly classified by the cycle test (29.5 and 29.3 ml/kg/min). Eighteen of the males were found to be excellent in fitness (50+ ml/kg/min ml) and 16 of them scored 50+ ml/kg/min on the cycle test as well. Cycle vs. treadmill scores for the other two highly fit men are summarized below:

Subject A:	Treadmill = 51.9 ml/kg/min	Cycle = 39.0 ml/kg/min
Subject B:	Treadmill = 52.6 ml/kg/min	Cycle = 48.8 ml/kg/min

Thus, subject A's $\dot{V}O_{2\,max}$ was clearly underestimated by cycle ergometry while subject B would be considered fit by either test. Four other men, demonstrating that they were above average with treadmill scores for $\dot{V}O_{2\,max}$ exceeding 45 ml/kg/min were clearly underestimated by cycle ergometry as shown below:

Subject C:	Treadmill = 49.3 ml/kg/min	Cycle = 35.9 ml/kg/min
Subject D.	Treadmill = 49.3 ml/kg/min	Cycle = 34.8 ml/kg/min
Subject E:	Treadmill = 45.6 ml/kg/min	Cycle = 38.4 ml/kg/min
Subject F:	Treadmill = 46.6 ml/kg/min	Cycle = 36.7 ml/kg/min

Although men with test scores like subjects A, C and F, may be rare, representing less than 9% of this sample population, they do appear in a normal population and are likely to achieve cardiovascular fitness values from cycle ergometry that clearly underestimate their true $\dot{V}O_{2\,max}$. Some possible reasons for these discrepancies will be suggested in the discussion section of this paper.

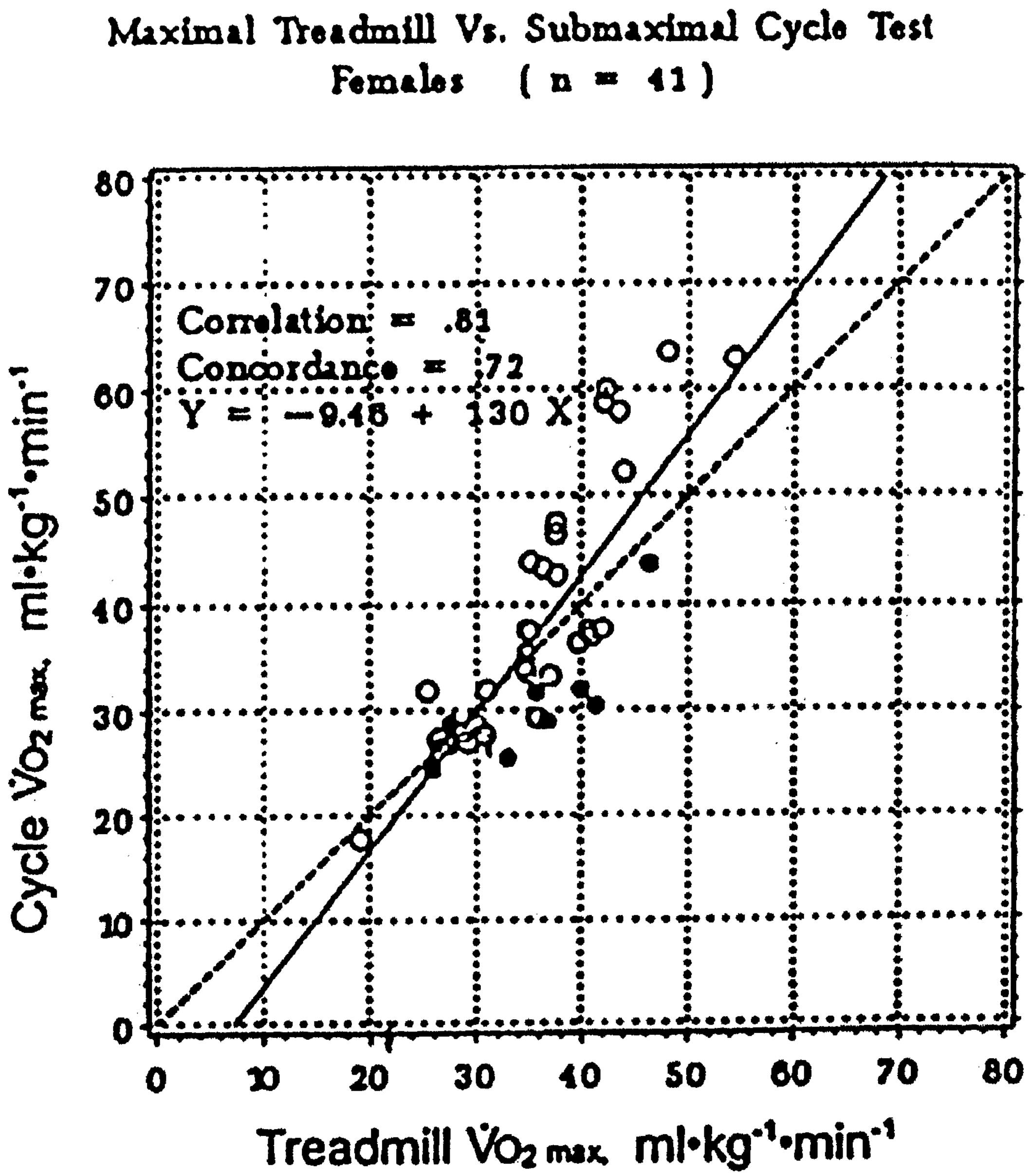

Figure8. Median values for female $\dot{V}O_{2\,max}$ estimated by submaximal exercise on a cycle ergometer plotted against the criterion values determined by indirect calorimetry during maximal treadmill exercise and compared with the line of identity (dashed line). Filled circles are self-selected subjects.

The regression line and data plotted in Figure 8 suggest that females low in fitness are quite accurately classified by cycle ergometry while $\dot{V}O_{2\,max}$ is significantly overestimated in their more highly-trained athletic counterparts. All but one of the females scoring 42+ on the treadmill were overestimated by at least 8 ml/kg/min by cycle ergometry. It should be noted that none of the 13 females scoring below 32 ml/kg/min on the treadmill scored higher than 32 ml/kg/min on the cycle. It is also interesting to note that the very least fit subject in this study had a treadmill score of 19.2 ml/kg/min; her estimated $\dot{V}O_{2\,max}$ by cycle ergometry was a very similar 17.7 ml/kg/min.

II. Practical Evaluation of Cycle Ergometry

In a practical sense, young men and women who are bona fide athletes in training as evidenced by high levels of success in competitive track events requiring superior cardiovascular fitness will score well on tests that validly measure aerobic capacity. On the other hand, it is certain that older, but healthy sedentary adults, and older adults who are also sedentary and suffering from chronic illness will score low on tests that validly assess cardiovascular fitness. Data collected from examples of both of these diverse groups provide a unique opportunity to exercise common sense in judging the "reasonableness" of $\dot{V}O_{2\,max}$ values for these subjects as estimated by cycle ergometry.

A. Competitive Athletes: Available for only a single experiment, the cycle ergometry protocol used in this study was administered to a group of highly successful competitive athletes on a morning following approximately two weeks of strenuous endurance, agility, and strength training. Summaries of the results of these tests and for six of their coaches (master athletes still in training) are presented in Tables 9 and 10, respectively.

Table 9. Cycle Ergometry Test Scores for 17 Male and 1 Female (f) Air Force Competitive Athletes.

Subject	Age (yrs)	Wt (kg)	Ht (in)	$\dot{V}O_{2\,max}$ (ml/kg/min)	Air Force Fitness Category*	Training Regimen (running average miles/week)
1	31	68.5	60.0	80.7	VI	40
2	23	69.0	71.0	65.3	VI	15
3	23	67.7	68.0	64.2	VI	20
4	37	73.2	69.5	57.1	VI	30
5	27	84.1	75.0	59.4	VI	20
6	35	71.1	71.0	59.0	VI	15
7	24	78.9	72.0	79.9	VI	30
8	26	70.4	69.0	67.3	VI	15
9	29	67.3	70.0	74.2	VI	30
10	34	72.6	69.0	55.9	VI	25
11	27	74.4	70.0	67.2	VI	25
12	27	69.9	68.0	61.3	VI	20
13(f)	36	50.6	63.0	73.9	VI	30
14	29	65.6	69.0	74.3	VI	35
15	35	74.7	70.0	70.5	VI	30
16	33	71.0	71.0	66.9	VI	35
17	39	79.1	73.5	58.0	VI	20
18	30	73.3	70.0	53.9	VI	12
Mean	30.28	71.19	69.89	66.06		24.8
S.D.	4.97	6.94	2.49	8.20		8.1
Minimum	23	50.6	63.0	53.9		12
Maximum	39	84.1	75.0	80.7		40

*The highest of six fitness categories in the original table of Air Force fitness standards initiated 1 Oct 1992. These standards were developed from field research study by Myhre[16] which provided fitness data representing a cross section of the U.S. Air Force.

From Table 9 it is noted that these 17 male and 1 female athletes ranged in age from 23 to 39 years. Their regular training regimens included "quality" running (i.e., at less than 7.50 min/mile pace) ranging from 12 to 40 miles per week for the past year or more. The cycle estimates of $\dot{V}O_{2\,max}$ for these athletes ranged from 53.9 ml/kg/min to 80.7 ml/kg/min, averaging 66.1 ml/kg/min. Although not treated statistically, the highest score was exhibited by the athlete running at least 40 miles per week and the lowest score by the athlete running only 12 miles per week. There is absolutely no question but that everyone of these subjects was highly fit; there is absolutely no question but that cycle test scores classified everyone of them as being highly fit (i.e. Air Force Fitness Category VI). The "master" athletes (coaches) presented in Table 10 exhibit fitness scores that are representative of men who continue to maintain a very vigorous exercise regimen. Five of these men were classified as being highly fit (i.e., Air Force Fitness Cat. VI) and the lowest score was still representative of high fitness (i.e., Air Force Fitness Cat. V).

Table 10. Cycle Ergometry Test Scores for 6 Members of the U.S. Air Force Male Pentathlete Coaching Staff.

Subject	Age (yrs)	Wt (kg)	Ht (in)	$VO_{2\,max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Air Force Fitness Category	Training Regimen (running average miles/week)
19	47	83.5	70.0	46.2	V	10
20	44	72.6	70.0	55.1	VI	12
21	52	63.4	67.0	50.4	VI	7.5
22	44	72.3	73.0	53.6	VI	15
23	43	82.8	72.0	51.5	VI	25
24	45	67.5	69.0	52.2	VI	10
Mean	45.83	73.68	70.17	51.5		13.25
S.D.	3.31	8.08	2.14	3.07		6.27
Minimum	43	63.4	67.0	46.2		10
Maximum	52	83.5	72.0	55.1		25

B. Elder, Sedentary Adults: The authors of this study collaborated with clinical investigators at the Wilford Hall Medical Center in setting up a testing facility to implement this computer-guided cycle ergometer program for estimating cardiovascular fitness in older adults. This experimental group consisted of volunteers from an Air Force patient population of 38 males and 41 females ranging in age from 39 to 84 years. Approximately half were diabetics and the remainder classified as "patient volunteers". All except one 41 year-old male jogger were primarily sedentary in lifestyle; the results of cycle test scores for these subjects are summarized in Table 11.

Table 11. Cycle Ergometry Test Scores for Patient Volunteers in a U.S. Air Force Study[13] to Assess the Effectivness of Exercise Programs as Therapy for Diabetics.

Group	N	Gender (male/female)	Age Mean ± S.D.	$Vo_{2\,max}$ (ml·kg^{-1}·min^{-1})	
				Mean ± S.D.	Minimum-Maximum
Diabetic Patients	23	(14/9)	57 ± 11	19.00 ± 3..50	9.5 – 25.0
Mostly Sedentary Patients	23	(14/9)	57 ± 11	21.20 ± 3..50	6.7 – 28.6 (44.3*)
Sedentary Diabetic Patients	16	(4/12)	57 ± 5	16.44 ± 4.50	5.0 – 21.8
Sedentary Patients	17	(6/11)	62 ± 7	16.96 ± 3.40	11.2 – 23.3

*44 year-old jogger treated independently in this group.

From Table 11 it can be seen that, except for the jogger, the highest cycle ergometry test score achieved by these sedentary patients was 28.6 ml/kg/min group averages ranging from 16.4 to 21.2 ml/kg/min equate to the lowest Air Force Fitness Category (Category 1). There is absolutely no question but that all but one of these subjects were either low or very low in physical work tolerance and their cycle test scores ranging from a low of 5.0 ml/kg/min to 28.6 ml/kg/min are representative of a very low level of cardiovascular fitness. Even the lone male jogger in this group was identified correctly by cycle ergometry.

DISCUSSION

A measure of aerobic capacity is an absolutely necessary component in any equation which purports to measure physical readiness to perform strenuous physical tasks. It remains scientifically unchallenged as the best single measure for describing basic physical fitness while being essentially the only measure for precisely describing one's cardiovascular capacity to support a sustained strenuous physical effort. This measure also has a high degree of clinical significance because of its unique ability to provide an objective assessment of the functional capacities of the myocardium, the vascular, and the respiratory systems. However, the personal, occupational, and clinical values provided by knowledge of this physiological parameter are essentially denied to all but a few because of the technical difficulty, the risk, and the expense involved in its measurement.

In lieu of a precise determination of aerobic capacity, the estimation of this parameter by heart rate responses to submaximal exercise is an attractive alternative because of its ease of administration, relative safety, and cost effectiveness. However, as with any estimate, absolute validity is neither assured nor is it expected. This study was conducted to evaluate a specific computer-guided protocol for estimating aerobic capacity from heart rate responses to a six-minute bout of precise, submaximal exercise on a cycle ergometer. This effort was primarily concerned with determining the safety, reliability, and the validity with which this specific cycle protocol provides an estimate of aerobic capacity in military-aged men and women.

I. Test Safety:

The *optimal safety inherent in this specific cycle protocol* is evident as summarized in Tables 2 and 3 which demonstrate the relatively moderate levels of physical exertion imposed on the subjects. The American College of Cardiology and The American Heart Association[1], and The American College of Sports Medicine[2] concur that regular exercise for 20 minutes or longer, at intensities which result in heart rates up to 85% of predicted maximal levels, is optimally safe and beneficial, requiring neither medical clearance nor supervision for adults who are essentially at low risk and asymptomatic with respect to heart disease. The work loads imposed by the cycle protocol in this study elicited heart rates which averaged about 140 beats per minute, or about 77% of the subjects' predicted maximal heart rates, and then for less than six minutes in duration. Since maximal heart rates were actually determined for these subjects, it is possible to report that the average exercise heart rates during these tests were precisely 74% and 76% of maximum for the males and females, respectively. The highest individual heart rate observed was still only 86.3% of the determined maximal heart rate for that subject, and this rate was maintained for less than two minutes. *Thus, It can be concluded that this cycle test protocol guides the selection of work loads which meet optimal safety standards;* subjects are required to reach only moderate levels of cardiovascular stress where peak heart rates will not exceed 85% of maximum.

II. Protocol Validity:

The procedural validity of any protocol to be used for estimating $\dot{V}O_{2\,max}$ *from heart rate responses to submaximal exercise* is dependent upon (1) the subject exercising at a load high enough to raise heart rates above 125 bpm, (2) the heart rate reaching a steady state (i.e., ± 3 beats per minute) during the final two minutes of exercise, and (3) test duration limited to 10 minutes or less. This computer guided program is designed to deal with the broad spectrum of human variability in identifying the most appropriate test work load for each individual, and all of the aforementioned requirements were met. From a total of 264 cycle tests administered in this study, heart rates reached an average of 140 and 142 bpm for the males and females, respectively, and the rates recorded during the last minutes of exercise differed by only 1 bpm; all tests were completed in 10 minutes or less. Thus, it can be concluded that *this specific test protocol guides the subject to exercise at a work load that can be considered optimal with respect to procedural validity,* i.e., valid intensity of effort and heart rate achieving a true steady state during the final minutes of the test. [Note: The procedural validity discussed here is not to be confused with the validity of the test scores which will be discussed later where cycle scores are compared with the criterion, i.e., maximal treadmill test scores.]

III. Test Reliability:

The reliability or repeatability of scores achieved from multiple administration of the cycle test was determined from data obtained when 77 of the subjects repeated this test on three separate occasions within a period of a few weeks. *Although these scores were impressively consistent, they tended to improve after the first attempt; differences averaged + 1.4* ml/kg/min *for the males and +1.6 for ml/kg/min the females.* These mean differences were small, but they were statistically significant and a few of the subjects benefited quite markedly from this possible "learning effect". It should be noted here that even the criterion method was not without a trend or learning effect; differences in repeated treadmill scores averaged +1.1 ml/kg/min for the males and +0.7 ml/kg/min for the females; only the gains observed for the males were statistically significant.

The confidence that can be placed in any given score achieved by either the cycle or the treadmill test can be estimated by analyses that determine the root mean square error term. From these data it was found that one could be 95% confident that a score for $\dot{V}O_{2\,max}$ achieved on a given maximal treadmill test would not differ from that subject's true score by more than ±2.8 ml/kg/min for both males and females. The corresponding confidence limits determined for cycle tests were, not unexpectedly, wider being ±5.2 ml/kg/min for the males and ±4.4 ml/kg/min for the females. From these data it may be concluded that it is quite likely that the average individual may gain 1-2 ml/kg/min by simply repeating the cycle test a second or third time. However, for even the more variable subjects, it is highly unlikely that scores from repeated attempts will ever improve by more than 5.2 ml/kg/min for males or 4.4 ml/kg/min for females.

IV. Test Validity:

The *validity of the estimates of* $\dot{V}O_{2\,max}$ values obtained from this specific cycle protocol was determined by analyzing the extent to which they agreed with the criterion measures. For this reason, it was deemed necessary to give every subject the opportunity to have a second or third attempt at reaching his/her maximal effort in the treadmill test. Seventy-one of the subjects in this study completed three treadmill tests and 16 completed two tests; data from a single maximal treadmill test were limited to only 10 of the male and 2 of the female subjects. The fact that the average peak heart rates observed during the maximal treadmill tests exceeded the predicted maximal heart rates for these subjects suggests a true maximal performance; the fact that the $\dot{V}O_{2\,max}$ values achieved during three separate attempts at these tests differed by an average of only about 1 ml/kg/min provides further evidence which suggests both (1) precision in the experimental methods and procedures, and (2) the dependability of these subjects to exert a maximal effort in performing these tests.

A. Tests Administered In Triplicate: It may be necessary to further explain the selection of the median values for comparing repeated treadmill and cycle test scores. Perhaps due to expense, technical difficulty, and the reluctance of subjects to repeatedly push themselves to the extraordinary discomfort accompanying exhausting exercise, previous research comparing estimates of $\dot{V}O_{2\,max}$ from submaximal cycle exercise with criterion values obtained from maximal treadmill experiments tend to rely on single experiments for both tests. Our experience with the learning effect associated with exercise tests convinces us that single attempts at a maximal effort can introduce the confusing element of subjectivity when seeking to determine one's physiological (as opposed to psychological) limit for consuming oxygen. Thus, allowing up to three attempts to achieve a maximal effort, our subjects demonstrated the value of the learning effect in that most scores improved on the second and/or third trials. Accepting the first attempt at a maximal treadmill test would have introduced a statistically significant error, underestimating the true aerobic capacity of most of our subjects. However, when dealing with units as small as a few milliliters, these differences may not be of practical significance, i.e., they may be the result of pushing the physical precision for measuring expired volumes and composition beyond state-of-the-art limits. Thus, for repeated measures, the median, rather than the first, the highest, or the mean, was deemed to be the most physiologically acceptable value representing an individual's true aerobic capacity. It may be argued that, since previous research in this area did not incorporate our rationale for repeated attempts to achieve a maximal effort for the treadmill test, only our first test scores can relate to previous work. On the other hand, it could also be argued that if repeated measures are involved, the most representative score would be the mean and not the median. Finally, since the definition of the term $\dot{V}O_{2\,max}$ is "maximal oxygen consumption", perhaps only the highest score achieved on either the treadmill or cycle tests should have been selected for analysis. Although we feel comfortable with our decision to use median values, analysis using first, mean, and maximal scores were also conducted and they are summarized in Table 12.

Table 12. Comparison of Methods for Analyzing Scores for $\dot{V}O_{2\,max}$ from Repeated Maximal Treadmill and submaximal Cycle Tests. (Values are means ±S.D.)

Males (n=58)				
	Treadmill $ml \cdot kg^{-1} \cdot min^{-1}$	Cycle $ml \cdot kg^{-1} \cdot min^{-1}$	Correlation*	Concordance
First test score	45.63 ± 19.11	43.97 ± 12.62	0.85	0.82
Mean score for all tests	46.05 ± 9.99	44.76 ± 12.31	0.87	0.84
Median Score for all tests	46.11 ± 10.02	44.76 ± 12.25	0.87	0.84
Maximum score for all tests	46.86 ± 10.04	46.35 ± 12.78	0.86	0.84

*Mean differences not significant; correlations highly significant ($p<0.001$).

Table 12 (continued)

Females (n=41)				
	Treadmill $ml \cdot kg^{-1} \cdot min^{-1}$	Cycle $ml \cdot kg^{-1} \cdot min^{-1}$	Correlation*	Concordance
First test score	35.27 ± 7.45	35.93 ± 11.35	0.81	0.74
Mean score for all tests	35.61 ± 7.16	36.73 ± 11.24	0.81	0.73
Median score for all tests	35.58 ± 7.17	36.91 ± 11.48	0.81	0.72
Maximum score for all tests	36.71 ± 7.39	38.20 ± 11.38	0.79	0.71

*Mean differences not significant; correlations highly significant ($p<0.001$).

The analyses of data in Table 12 confirm the previously discussed high reliability of test scores obtained from both maximal treadmill and submaximal cycle tests. Thus, it is not surprising that the mean difference between treadmill determinations and cycle estimates of $\dot{V}O_{2\,max}$ remained small and insignificant regardless of which of the scores was selected for statistical analyses.

Correlation values also remained relatively constant and highly significant as did the values for concordance. Comparing median scores for all tests, the correlations between the cycle estimate and the treadmill criterion were 0.87 and 0.81 for the male and female subjects, respectively. Although these values were highly significant, it should be noted that the volunteer subjects were not as randomly selected as intended. Indeed, 17 of the males and 8 of the of females were self-selected in the sense that they entered this study because they had personal reasons to suspect that their aerobic capacities were being significantly underestimated by cycle ergometry. From a total pool exceeding 2000 military personnel assigned to Brooks AFB who had already been required to take this same cycle test administered as the Air Force cycle ergometry test, these individuals represented what might be described as being among the most dissatisfied with their cycle test scores. As with any estimate that depends upon assumed constants for physiological parameters, the validity of that estimate suffers when applied to individuals whose physiology differs greatly from the norm. With this in mind, it was decided to have a look at the correlations between the estimate and criterion values for just those subjects who entered this study by the normal procedure, i.e., advertising for volunteers. In that case, the correlations for the men ($n = 41$) and women ($n = 33$) were 0.90 and 0.87, respectively. Although it is not the intent to drop the self-selected subjects from consideration in this study, this does suggest that the correlations of 0.87 and 0.81 observed for this entire sample of men and women, respectively, may be a bit lower than would be expected in a truly normal sample of the population.

Although repeated attempts to determine true $\dot{V}O_{2\,max}$ from maximal treadmill tests may not have been necessary in this study, they nevertheless provide a high degree of confidence in the validity of this criterion measure, and thus, a high degree of confidence in the determined relationship between it and the cycle estimate of $\dot{V}O_{2\,max}$.

B. Human Variability: The facts that (1) there was no significant difference between the mean scores achieved by maximal treadmill and submaximal cycle tests, for either gender, and (2) there was a relatively high correlation between estimated and determined $\dot{V}O_{2\,max}$ scores are encouraging. However, it was found that for some subjects cycle ergometry significantly under- or overestimated their true $\dot{V}O_{2\,max}$ and these discrepancies did not disappear with repeated (learning) attempts.

1. Stroke Volume/Oxygen Pulse: Subjects whose true $\dot{V}O_{2\,max}$ was significantly higher than that estimated by cycle ergometry exhibited relatively high heart rates during relatively easy exercise, and this presents a dilemma of sorts. Our data do not provide information about cardiac output, but one can calculate the oxygen pulse from submaximal cycle and maximal treadmill exercise, and these data are presented in Table 13.

Table 13. Summary of Oxygen Pulse Values Calculated for Submaximal Cycle and Maximal Treadmill Exercise Tests. (Means ±S.D.)

	Oxygen Pulse (for submaximal exercise) ml/beat	$\dot{V}O_{2\,max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Oxygen Pulse (for maximal exercise) ml/beat	$\dot{V}O_{2\,max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
Summary of All Data				
Males (n=58)	15.34 ± 3.37	43.08 ± 11.60	19.08 ± 3.80	46.99 ± 10.62
Females (n=41)	9.58 ± 22.40	37.08 ± 11.48	11.84 ± 2.57	36.45 ± 7.20
Male and Female Subjects with the Lowest Cycle Estimates of $\dot{V}O_{2\,max}$				
Males (n=5)	13.39 ± 2.78	31.08 ± 2.47	16.18 ± 2.37	37.06 ± 6.58
Females (n=5)	8.98 ± 0.59	24.72 ± 4.21	10.98 ± 0.77	25.12 ± 3.34
Male and Female Subjects with the Highest Cycle Estimates of $\dot{V}O_{2\,max}$				
Males (n=5)	21.77 ± 4.31	68.52 ± 5.14	25.46 ± 2.14	64.18 ± 3.10
Females (n=5)	15.05 ± 1.93	59.66 ± 4.07	16.18 ± 2.68	46.46 ± 4.95

Calculating the oxygen pulse provides a measure of cardiovascular efficiency. In these experiments, dividing the oxygen requirement in performing the submaximal cycle tests by heart rate results in values for oxygen pulse averaging 15.3 and 9.6 ml/beat for the males and females, respectively.

As shown in Table 13, the oxygen pulse increased significantly when the subjects performed maximal treadmill exercise. The relatively low oxygen pulse values exhibited by the least fit subjects during the cycle tests were confirmed by their similar responses to maximal treadmill exercise. Similarly, the highly fit subjects exhibited oxygen pulse values that were significantly higher than the least fit subjects in both cycle and treadmill exercise.

The higher values for oxygen pulse observed in the maximal treadmill exercise for both the highly fit and the less fit subjects must have been due to corresponding increases in stroke volume and/or greater efficiency in the uptake of oxygen from a given volume of blood, i.e., greater arterio-venous oxygen (a-v O_2) difference in the maximal treadmill exercise.

The fact that the highly fit subjects exhibited significantly higher values for oxygen pulse than did the less fit subjects in both submaximal cycle and maximal treadmill exercise suggests that the low cycle scores are at least in part the consequence of a relatively low stroke volume, and thus, a relatively less efficient cardiovascular performance during submaximal exercise. (The alternative hypothesis would be a normal stroke volume but a below normal value for a-vO_2 difference; neither would be a welcomed state.)

2. "High" Pre-Test Heart Rate: The formula for calculating an estimated $\dot{V}O_{2\,max}$ from steady state heart rate and cycle load (i.e., metabolic requirement) includes a factor that assumes a constant, normal resting heart rate. It is possible, indeed probable, that anything that would cause the pre-exercise heart rate (i.e., the value observed following two minutes of sitting quietly on the cycle prior to the test) to be excessively high would not only violate the resting heart rate assumption, but could be responsible for some error in estimating $\dot{V}O_{2\,max}$ as well. Whether or not the higher than normal resting heart rate would carry over to a higher than normal exercise heart rate for a given individual is probable, but not certain. First, if the pre-exercise heart rate is a little high it may simply be due to the very normal 'anticipatory" response to the pending onset of exercise as first noted by Robinson[11] in the 1930's. This elevation in heart rate is generally transitory, usually blending in to a perfectly normal proportional heart rate-to-work load response shortly after exercise has begun. Robinson[11] also suggested that this anticipatory increase in heart rate, which was obviously due to non-exercise nervous/emotional stimuli, could have an additive effect on exercise heart rate within the limits of the vagus nerve's capability to influence cardiac pacemaker activity. The total release of the vagus' inhibitory tone was first observed in man when Robinson[11] chemically disabled his vagal innervation by an intramuscular injection of atropine. His normal resting heart rate of 40-50 bpm immediately increased to about 120 bpm, but no higher. This "denervated" heart then responded quite normally to exercise, reaching the same maximal value as observed in maximal exercise prior to the atropine experiment. Thus, emotional stimuli can cause an increase in heart rate by reducing vagal tone, but completely removing all vagal tone by chemically "severing" the vagus with atropine indicates that beyond a heart rate of 120 bpm, the vagus can no longer respond to emotional stimuli. Consequently, although emotional stimuli may alter normal heart rate response to exercise, that error becomes progressively less important when exercise heart rate reaches or exceeds 120 bpm. For this reason this cycle protocol requires that the cycle load be increased to a point assuring that heart rate will exceed 125 bpm if the test is to be considered valid.

In this study, true resting heart rates were accurately determined under classical basal metabolic conditions. These heart rates were then used as a reference for noting possible individual pecularities in preexercise heart rate. It was assumed that pre-exercise heart rate should reflect true resting values fairly well; when the difference between them becomes excessive (i.e., perhaps greater than 20 bpm) a valid cycle estimate of $\dot{V}O_{2\,max}$ becomes increasingly worrisome. If the increase prior to exercise is merely in anticipation of the exercise, it was deemed probable that the increase would not be additive (and therefore not of any significant effect) providing the exercise heart rate exceeded 125 bpm. However, if the increase prior to exercise has some other underlying cause, i.e., infection, arrythmia, or other factors that would not be expected to disappear with exercise, the effect would almost certainly affect the exercise heart rate, and consequently, would result in an invalidly low estimate $\dot{V}O_{2\,max}$. To further explore this possibility, heart rate data from subjects who completed the basal metabolism experiments were compared with the pre-exercise heart rates observed for those same subjects; these data are presented in Table 14.

Table 14. Resting Heart Rates Recorded During Basal Metabolism Experiments vs. Heart Rates Recorded for the Same Subjects Immediately Prior to the Onset of Cycle Exercise: Possible Effect on Test Score. (Mean ± S.D.)

	Resting Heart Rate, bpm Mean ± S.D.	Correlation (Resting HR vs Cycle Test Score)
Males (n=37)	55.4 ±9.9	-.67**
Females (n=37)	61.3 ±9.1	-.64**
	Pre-Test Heart Rate, bpm Mean ± S.D.	Correlation Pre-Test HR vs Cycle Test Score
Males (n=37)	66.6*±10.3	-0.76**
Females (n=37)	73.6*±12.8	-0.61**

*Difference significant (Paired T-Test $p<0.05$)

**Correlation significant ($p<0.05$)

Table 14 shows that the average differences between supine resting heart rate and the heart rate observed while seated quietly on the cycle immediately prior to the test were approximately 11 and 12 bpm for the males and females, respectively. The negative correlations indicate that a high heart rate, whether observed either in a true resting state or immediately before beginning the test, predicts a low cycle ergometry estimate of $\dot{V}O_{2\,max}$. Thus, these data suggest that a higher than average resting and/or pre-test heart rate is a harbinger of a low (relative) score in a cycle test, and it is postulated that this low score is relatively valid if the high heart rate is normal for and representative of the individual.

The significance of these data is obscured somewhat because of the lack of a definition for a high or low heart rate. One might reason that a pre-test heart rate that is excessively high would tend to have a more negative effect than one which is within a beat or two from one day to the next. Indeed, in the present study, most subjects exhibited only small differences in day-to-day pre-test heart rates. The potential value of the pre-test heart rate as a predictor of cycle test validity demands further attention. Table 15 gives a summary of slopes constructed for each subject completing multiple cycle tests. A negative slope indicates that, for a given subject, arriving with a high pre-test heart rate results in a lower cycle test score than when, on another occasion, that same subject arrived with a lower pre-test heart rate.

Table 15. The Direction of Relationship Between Pre-Test Heart Rates and $\dot{V}O_{2\,max}$ Scores Achieved on the Submaximal Cycle Test.

Difference Between Highest and Lowest Pre-Test Heart Rates (bpm).		Negative	None	Positive	
Males	(<10)	16	11	16	NS
Males	(≥10)	13	0	2	$p<0.01$
Females	(<10)	10	1	11	NS
Females	(≥10)	16	0	3	$p<0.01$

Table 15 illustrates that, for multiple attempts at the cycle ergometer test, arriving with pre-test heart rates that differed by less than 10 bpm had no significant effect on the resulting estimate of $\dot{V}O_{2\,max}$. However, when the pre-test heart rate exceeds the lowest observed pre-test heart rate by more than 10 bpm, the probability of achieving a lower cycle score is highly significant, but not necessarily remarkable. For example, for the data in Table 15 only 5 of the 13 males and 1 of the 16 females exhibiting an occasionally high pre-test heart rate had estimates of $\dot{V}O_{2\,max}$ that were more than 5 ml/kg/min lower than their best scores. From a more practical standpoint, Table 16 presents case study examples of two individuals exhibiting the most obvious variability in pre-test heart rate values along with their apparent effect on cycle test scores.

Table 16. Examples of Repeated Submaximal Cycle Erogmeter and Maximal Treadmill Test Results for Subjects Exhibiting Wide Variability in Pre-Test Heart Rate.

Date	Pre-Test Heart Rate* bpm	Submaximal Cycle Test $\dot{V}O_{2\,max}$ ($ml\cdot kg^{-1}\cdot min^{-1}$)	Maximal Treadmill Test $\dot{V}O_{2\,max}$ ($ml\cdot kg^{-1}\cdot min^{-1}$)
Male Subject #6			
8-25	92	29.5	39.2
8-26	75	36.2	40.1
9-3	62	43.5	40.0
9-8	80	42.1	
9-22	78	34.4	
10-5	104	29.6	
11-9	84	35.0	

11-10	72	42.5	
Female Subject #12			
6-1	104	23.4	26.5
6-4	84	27.3	
6-6	82	30.8	
6-22	98	26.1	

*Resting heart rates during basal metabolism experiment were 62 and 66 bpm for subjects 6 and 12 respectively.

Subject #6 in Table 16 is a 20 year-old sedentary male who repeatedly scored unreasonably low in his required military cycle tests. Records showed that his Air Force pre-test heart rates were always high, usually exceeding 100 bpm. Twenty-four hour Holter monitoring revealed nothing particularly remarkable about his EKG, but it did confirm a higher than normal resting heart rate. Further clinical examinations were not recommended. The young man then entered this study and his true resting heart rate (i.e., under the controlled conditions of the basal metabolism experiment) was 62 bpm. His pre-test heart rates were so variable that it was deemed necessary to continue to study him beyond the normal triplicate measures for cycle ergometry. His highest cycle ergometer test scores (≈42 ml/kg/min) were achieved on days when his pre-exercise heart rates were within 18 bpm of his true resting heart rate; lowest scores (≈30 ml/kg/min) occurred on days when pre-exercise heart rates were 30 or more bpm higher than true resting values.

Subject #12 in Table 16 is a 28 year-old sedentary female whose medical clearance to enter this study had somehow overlooked her anemic condition as evidenced by a hemoglobin concentration of 9.6 g%. Her true resting heart rate was recorded as 66 bpm; variability in pre-test heart rate and her relatively low cycle and treadmill values for $\dot{V}O_{2\,max}$ could well have been at least partially attributed to the obvious reduction in the oxygen carrying capacity of blood low in hemoglobin. Experiments involving this subject were ceased and she was referred to the Base Clinic for treatment and observation. Again, but this time perhaps for an objective clinical reason, the tendency for lower cycle test scores on days with higher pre-test heart rates persists.

The average difference between accurately determined resting heart rate and the pre-exercise heart rate for 74 subjects was only 12 bpm; pre-exercise heart rates of 92-104 bpm for a subject whose resting rate is only 62 strongly suggests something more than mere day-to-day variability. Such differences are simply not normal and they may reflect other unknown problems that might be responsible for invalidly low estimates of $\dot{V}O_{2\,max}$ by cycle ergometry. Subject #6 is a young man who begins his work day at 0400 hrs may simply be physiologically/psychologically disagreeable for him, and this may be reflected by his occasional arrival with tachycardia at test time (0800-0900 hr).

Whatever the reason, it appears evident that a subject whose pre-test heart rate is abnormally high, (i.e., more than 20 beats higher than his/her true resting heart rate) is physiologically and/or psychologically incapable of a valid performance in this submaximal cycle test. It may be tempting for some to suggest that the absence of a pre-exercise heart rate that closely reflects true resting heart rate is indeed quite normal and test validity should not be affected by it. In response to this hypothetical statement it must be remembered that the average difference between true resting and pre-exercise heart rates in this study was only 12 bpm; differences greater than this amount may be suspect. Next, it should be noted that the eight competitive male athletes included in this study, a subgroup that unquestionably exemplifies those with the highest levels of cardiovascular fitness in our society, had no difficulty presenting themselves with normal heart rates prior to the cycle test; mean ± S.D. values for this group were 46.8 ±6.1 and 53.3 ±8.2 bpm for resting and pre-exercise heart rates, respectively. The lowest estimate of $\dot{V}O_{2\,max}$ by cycle ergometry for this group was 55.6 ml/kg/min. From this one may conclude that athletes, whose physical training leads to high levels of cardiovascular fitness, exhibit relatively low resting heart rates (i.e., averaging 46.8 bpm) and rates that are only slightly higher (i.e., averaging 53.3 bpm) when resting on the seat immediately prior to the cycle test. Considerably greater variability in differences between pre-test and true resting heart rates do tend to appear in those representing low to merely moderate levels of cardiovascular fitness. In conclusion, pre-test heart rates that differ from a given individual's true resting heart rates by more than 20 bpm are not to be considered as normal for that individual and they tend to foretell a cycle estimate of $\dot{V}O_{2\,max}$ that may be more than just a few ml/kg/min lower than that determined by the maximal treadmill criterion. However, high initial heart rates cannot always be cited as a reason for failure to achieve a high-level fitness score by cycle ergometry; all of those with the pre-test heart rate "problems" in this study failed to achieve high scores on the criterion treadmill tests as well.

3. Invalid Estimate of Resting Heart Rate: Table 17 summarizes the practical effects of replacing an assumed constant resting heart rate with the observed pre-exercise heart rate; it did not effect the correlation between the cycle and criterion measures.

Table 17. Relative Effect of Utilizing Known Values for Resting Heart Rates vs. the Constants Employed by the Standard Formula for Estimating $\dot{V}O_{2\,max}$ from Submaximal Cycle Ergometry.

	Males (n=58)	Females (n=41)
Standard Calculation	0.87	0.81
Insert Individual pre-test Heart Rate	0.86	0.81
Insert Individual Resting (Basal) Heart Rate	0.88 (n=37)	0.81 (n=37)

The individual pre-test heart rates referred to in Table 17 are easy to obtain; they are simply recorded following two minutes of quite sitting on the cycle prior to initiating the exercise test. An individual's true resting heart rate is another matter since it requires that the subject be rested, post absorptive, and lying quietly for at least an hour under strictly controlled conditions. Since these measures were obtained in 74 of the subjects (37 males and 37 females) studied here, these true resting heart rates were substituted for the assumed constant in estimating $\dot{V}O_{2\,max}$. However, from Table 17 it can be seen that this had no effect on the correlation between estimated and criterion (treadmill) values.

V. Practical Application of the Cycle Test to Fit and Unfit Populations: Finally, the cycle ergometry test protocol studied here correctly identified individuals with high levels of aerobic capacity (i.e., >50 ml/kg/min as either determined by the maximal treadmill test or implicit in their demonstrated athletic performance); 100% of the 32 male athletes studied here scored higher than 53 ml/kg/min by cycle ergometry. Just as impressive was the fact that none of the 78 sedentary patients cited in this study scored higher than 28.6 ml/kg/min (they averaged only 16.4 to 21.2 ml/kg/min), and none of the male or female subjects scoring less than 32 ml/kg/min by maximal treadmill exercise scored higher than 32 ml/kg/min by cycle ergometry. Thus, neither the highly fit nor the very low fit individuals were categorically misjudged by cycle ergometry.

SUMMARY: This study's findings concerning the relative value of cycle ergometry for estimating aerobic capacity in military-aged men and women can be summarized as follows:

• The *safety* precautions inherent in this specific computer-guided protocol for estimating from $\dot{V}O_{2\,max}$ submaximal cycle ergometry are impressively effective; work loads selected by this protocol imposed a level of stress that elicited heart rates averaging about 75% of maximum, and the highest heart rate observed for any individual was less than 87% of maximum.

• The *reliability* or repeatability of test scores was excellent; when given three attempts, most subjects tended to improve following the first test, but the magnitude of that improvement was slight, averaging only 1.4 for the males and 1.6 ml/kg/min for the female subjects in this study. One can be 95% confident that any given score will be within 5.2 ml of the true cycle score for men and within 4.4 ml/kg/min for women.

• The *overall test validity* can be summarized as follows: Determinations of $\dot{V}O_{2\,max}$. by the criterion method (maximal treadmill test) averaged 46.1 ml/kg/min for the male and 35.6 ml/kg/min for the female subjects in this study. Corresponding values estimated from cycle ergometry were 44.8 ml/kg/min and 36.9 ml/kg/min and the differences between these scores were not significant. Correlations between scores achieved by these two methods were 0.87 and 0.81 for the males and females, respectively. Excessive underestimates of $\dot{V}O_{2\,max}$ by cycle ergometry (i.e. by more than 10 ml/kg/min) were rare, but they did occur in 5 (9%) of the males and in 1 (2%) of the females in this study.

• From a *practical* viewpoint, this test may be considered as highly accurate in screening highly fit from low to pathologically low levels of cardiovascular fitness. Not a single male or female demonstrating athletic levels of cardiovascular fitness (i.e., $\dot{V}O_{2\,max} \geq 50$ ml/kg/min) by either maximal treadmill test results or by competitive athletic performance were misclassified by cycle ergometry. Similarly, not a single male or female demonstrating low levels of cardiovascular fitness (i.e., mean $\dot{V}O_{2\,max} < 30$ ml/kg/min) by either maximal treadmill test results or by clinical definition as being sedentary and/or frail (i.e., mean $\dot{V}O_{2\,max} < 22$ ml/kg/min) were misclassified by cycle ergometry.

• The estimation of $\dot{V}O_{2\,max}$ from heart rate responses to a precise bout of submaximal exercise assumes a constant or normal value for both resting and maximal heart rates. Determining true values for individual resting heart rate would require a carefully controlled experiment of about one hour in duration with a post-absorptive subject. Using these actual data rather than the assumed constants had little or no effect on the correlation between cycle estimates and treadmill determinations for $\dot{V}O_{2\,max}$ (see Table 17). It might be argued that for individuals who vary greatly from the norm, the knowledge of the determined value for maximal heart rate might greatly enhance the validity of the cycle estimate. However, this becomes an academic point because any experiment that would yield a true measure of maximal heart rate could also provide a true measure of $\dot{V}O_{2\,max}$, thus precluding the need for a cycle estimate.

• Although all athletes and all of the most sedentary of the subjects were correctly identified by their corresponding levels of $\dot{V}O_{2\,max}$ estimated by cycle ergometry, *some of those within the more average range of fitness achieved cycle test scores that were considerably lower than their values for* $\dot{V}O_{2\,max}$ *which were accurately determined from maximal treadmill exercise* by indirect calorimetry. Some, but not all of these discrepancies could be ascribed to subjects arriving for cycle testing in something less than a normal physiological/psychological state. Test validity is significantly compromised when individuals present themselves with abnormally high pre-test heart rates, and attempts to obtain meaningful data from cycle ergometry for these people may be futile. It is recommended that the cycle test be rescheduled any time an individual presents a pre-exercise heart rate that is more than 20 bpm higher than that known to be normal as determined during a true resting state. If the problem of high pre-test heart rate persists, other more direct methods for estimating/measuring cardiovascular fitness should be considered.

The most vocal concern for the difference between cycle estimates and treadmill determinations of aerobic capacity will undoubtedly be expressed by those whose true aerobic capacity (i.e. as evidenced by their effective exercise habits and physical performance capabilities) is obviously underestimated by a below average performance in the cycle test. Low cycle test scores are the result of high heart rate relative to energy cost; the most probable reason for this is a lower than average stroke volume since cardiac output during submaximal exercise is essentially the same for both trained and untrained individuals[2]. Further research is needed to fully explore the etiology of this variability in human cardiovascular response to exercise.

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APPENDIX 1

Algorithms for the Valid Estimate of Aerobic Capacity from Submaximal Cycle Exercise

Table 1. Selecting the Initial Work Load on a Precision Monark 818-E Cycle Ergometer.

Subject Weight lbs	Initial Work Load, kiloponds Male	Female
	18 to 35 years	
<100	1.0	1.0
100 -140	1.5	1.0
141 -170	2.0	1.5
>170	2.0	2.0
	36 to 55 years	
<100	1.0	1.0
100 -140	1.5	1.0
141 -170	2.0	1.5
>170	2.0	1.5
	56 to 62 years	
<100	1.0	1.0
100 -140	1.5	1.0
141 -170	1.5	1.0
>170	1.5	1.5

Table 2. Cycle Ergometer Load-Setting Guide for the First Minutes of the Test for Estimating Aerobic Capacity.

Time	Heart Rate (bpm)	Load Change (kiloponds)
I. 18-29 year age group		
End of minute 1	<105	+1.0
	105-114	+0.5
	115-130	0.0
	131-150	- 0.5
	>150	Stop Test
End of minute 2	<110 +1.0	
	110-119	+0.5
	120-135	0.0
	136-155	- 0.5
	>155	Stop Test

End of minute 3	<120 +1.0	
	120-129	+0.5
	130-145	0.0
	146-155	- 0.5
	>155	Stop Test

II. 30-39 year age group

End of minute 1	<100 +1.0	
	100-109	+0.5
	110-125	0.0
	126-145	- 0.5
	>145	Stop Test
End of minute 2	<105+1.0	
	105-114	+0.5
	115-130	0.0
	131-150	- 0.5
	>150	Stop Test
End of minute 3	<110	+1.0
	110-124	+0.5
	125-140	0.0
	141-150	- 0.5
	>150	Stop Test

III. 40-49 year age group

End of minute 1	<95	+1.0
	95-104	+0.5
	105-125	0.0
	126-140	- 0.5
	>140	Stop Test
End of minute 2	<100	+1.0
	100-109	+0.5
	110-130	0.0
	131-145	- 0.5
	>145	Stop Test
End of minute 3	<110	+1.0
	110-119	+0.5
	120-135	0.0
	136-145	- 0.5
	>145	Stop Test

IV. 50-62 year age group

End of minute 1	<190	+1.0
	90-99	+0.5
	100-120	0.0
	121-135	-0.5
	>135	Stop Test

End of minute 2	<100	+1.0
	100-109	+0.5
	110-130	0.0
	131-140	- 0.5
	>140	Stop Test
End of minute 3	<105	+1.0
	105-117	+0.5
	118-130	0.0
	131-145	-0.5
	>145	Stop Test

Table 3. Formula for Calculating Aerobic Capacity from Heart Rate Response to a Precise, but Submaximal Work Load on a Monark 818-E Cycle Ergometer.

Step #1: "A" - $Wt^{0.425} \times Ht^{0.725} \times 71.84 \times 10^{-4}$

Step #2: "B" - Load in kilopond meter/min x 10.18 = (670 x "A")

Step #3: "C" males = $\frac{144}{HR - 61}$ {Note: HR is the steady state heart rate at the load in "B" above.}

"C" female = $\frac{138}{HR - 72}$

Step # 4 "D" male = $\frac{100}{100 + \{1.37\,(\text{age}) - 33.2\}}$

D" female = $\frac{100}{100 + \{1.14\,(\text{age}) - 23\}}$

Step #5: $\dot{V}O_{2\,max}$ (ml/min, STPD) + B x C x D